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THE THERMAL CONDENSATION OF ACETYLENE IN THE PRESENCE OF POROUS ADDED SUBSTANCES

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The condensation of acetylene takes place with a decrease in volume, and therefore an increase in pressure must favor the formation of a condensate. But as acetylene explodes at comparatively slightly excess pressure [1] the use of high pressures is limited.

Zelinsky [2] suggested the replacement of dirrect pressure by indirect, by forcing heated acetylene to pass through a porous substance with a highly developed surface. As such a substance he used activated charcoal. Zelinsky was able to obtain a condensate in a yield of 70 to 74% by weight of the acetylene. It contained up to 35% of benzene and 4% of toluene.

These results were much superior to those which had been obtained by other investigators [3,4,5] before Zelinsky, and thus Zelinsky's suggestion about the favorable influence of activated charcoal on the process of thermal condensation of acetylene found what seemed to be experimental confirmation.

However, several authors [6,7,8] showed that the porosity of the charcoal had no essential significance, as with less porous substances, like coke, kaolin, pumice, brick, and porcelain, the same results were obtained as with activated charcoal or silica gel.

In the opinion of these authors, the actual catalyst which favored the condensation was the carbon which was formed in the process of pyrolysis on the surface of the different fillers.

Fischer [9] and also Lozovoi [10] observed that tar formation began only after long "preheating" of the activated charcoal (5 or 6 hours). According to Fischer, during the process of "preheating', the formation of a carbon layer took place on the activated charcoal, and this was the actual catalyst during the condensation.

In the opinion of Lozovoi [10] it was difficult to decide whether this carbon was the actual catalyst, or whether it was a product of further condensation which had no influence on the process.

Work by other investigators did not give the answer to this question, although it was noted [10,11,12] that in the case of the formation, during the pyrolysis of acetylene, of a dense shining film (crust) of charcoal, the condensation of acetylene to give tar took place with great intensity, and in the case of the formation in the reaction space of soot-like carbon, there was an insignificant yield of tar, and the acetylene was decomposed into its elements.

EXPERIMENTAL

As the raw material for pyrolysis we used the gas obtained by the decomposition of kerosene by Tatarinov's method [13,14] in the discharge of a voltaic arc. This gas had the following composition (in percent):

acetylene	33.1,	hydrogen	45.4,
ethylene	8.7,	carbon monoxide	0.6,
ethane	1.0,	propylene and n-butylene	2.9.
methane	8.3,		

The pyrolysis was carried out in a circulatory system which consisted of porcelain tubes heated in a round electric oven, with condensers, scrubbers, and receivers for the condensate and gas. The temperature was measured with thermocouples placed in the porcelain housing inside the reaction tube. The velocity of passage of the gas was noted by means of a meter and a rheometer.

The gaseous products of pyrolysis were analyzed for O_2, CO, CO_2, and saturated hydrocarbons, as is customary in gas analyses. The ethylene hydrocarbons were determined by the sulfuric acid method of Dobryansky [15], as modified by Markovich and Dementyeva [16]. Butadiene was analyzed by the method of Korotkova [17], with maleic anhydride.

The condensate from the receivers and the light hydrocarbons which distilled over with steam from the scrubber oil were first separated into fractions boiling up to 200° and beyond 200°, and the fraction up to 200° was then subjected to further fractionation into narrower distillates: 70-90, 100-120, 125-150°. In these the content of the corresponding aromatic hydrocarbons was determined.

Experiments with an Unfilled Porcelain Tube

For the process of pyrolysis, not only the temperature, but the time during which the material to be pyrolyzed remains in the reaction zone (duration of contact) has an important significance. However, the factor of time has not been taken into account by many investigators, who were frequently led to erroneous conclusions, and this makes difficult the comparison of the results of different investigators. Therefore, in a study of the influence of different factors on the process of pyrolysis, we endeavored to take strict account of the duration of contact, paying special attention toward making it the same in comparable experiments.

The duration of contact was computed from the formula [18]:

$$\tau = \frac{vT'}{FT''},$$

where τ is the time of contact, in seconds; v is the volume of the heated portion of the reaction tube, in milliliters; T' is the absolute temperature of the entering gas; T'' is the absolute temperature of the heated gas (temperature inside the reaction tube); F is the volume velocity of passage of the gas in ml/sec, equal to the average value of the volumes of the entering and leaving gas:

$$F = \frac{v_0 + v_k}{2}.$$

This in itself assumes a linear change in the volume of the gas along the reaction tube. As Vvedensky [19] has shown, the change in volume takes place according to a more complicated law, but taking into account the fact that in our experiments the acetylene was diluted to the extent of two-thirds with other gases, the volume of which changed little, the error in this approximation is insignificant.

In order to choose the optimal temperature, we carried out a series of experiments (Table 1) with a constant gas velocity of 1 liter per minute in a porcelain tube of diameter 32 mm, and a length of 800 mm of the heated part.

TABLE 1

Expt. No.	Temperature, (°)	Time of contact (sec.)	Gas passed (liters) (0.760)	Yield		Fraction up to 150° (% of condensate)	Aromatic hydrocarbons (% of condensate		
				Condensate (% of acetylene passed through	Charcoal (in % of acetylene passed through		Benzene	Toluene	Xylenes
6	400	15.7	227	10.4	3.94	63.0	0.00	0.0	0.0
7	500	13.9	268	18.7	10.40	55.6	3.26	0.0	0.0
8	600	13.0	212	33.2	9.04	44.3	26.2	9.5	5.66
9	650	12.7	258	48.3	12.81	44.4	29.8	5.75	3.32
10	700	12.5	286	65.8	10.40	38.6	28.2	3.45	2.34
11	750	12.4	182	53.8	26.50	37.6	29.1	1.86	1.59
12	800	10.9	181	46.9	36.60	40.0	35.8	0.72	–

As can be seen from Table 1, the condensation of acetylene began even at 400°, and the yield of condensate reached its maximum of 65.8% at 700°. With an increase in temperature above 700°, the yield of tar began to fall sharply. The temperature showed an influence not only on the quantitative but also on the qualitative composition of the products. Thus, at 400°, no aromatic hydrocarbons were observed at all; at 500°, benzene appeared, its amount increasing continuously with increase in temperature. Toluene appeared at 600°, and with a further increase of temperature its yield began to fall. This is apparently to be explained by secondary reactions of demethylation and condensation to ditolyl.

The optimal time for the acetylene to remain in the hot zone at 700°, as can be seen from the diagram of Fig. 1, was 12 seconds. With a shorter duration of contact, a large part of the acetylene did not enter into reaction, and with a longer time, the yield of lighter fractions of the tar was lowered, and the yield of heavy tar and coke was increased.

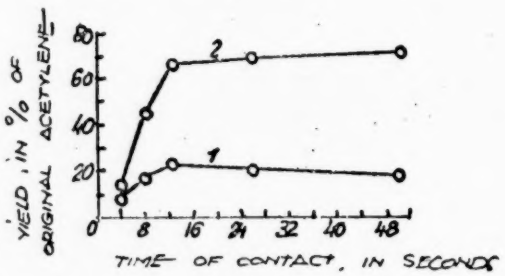

Fig. 1. Relationship of yield of products of pyrolysis to time of contact.

1) Fraction up to 150°; 2) condensate

The Pyrolysis of Acetylene Gas in the Presence of Added Substances

It was first of all of interest to elucidate how the proces would take place if the reaction tube were filled with an added substance of the same material. For this we utilized porcelain rings 6 x 6 x 3 mm. The addition of such rings filled up 45% of the useful volume of the reaction space [20], and this was taken into account in the determination of the duration of contact.

The results of the experiments carried out with added porcelain under the same conditions of time and temperature as for the empty porcelain tube show (Table 2) that not only the degree of decomposition of the acetylene, but also

TABLE 2

Pyrolysis of Acetylene Gas at 700° in a Porcelain Tube, Without Added Substances, and with Added Porcelain Rings

Expt. No.	Added substance	Duration of contact, seconds	Gas passed through (liters) (0.760)	Yield of condensate (% acetylene passed through)	Yield of carbon (% of acetylene passed through)	Yield of fraction up to 150° (% of condensate)
10	Without added substance	12.5	286	65.8	10.4	38.6
39	Porcelain rings	13.65	214	65.2	11.2	40.1
14	Without added substance	26.0	122	68.3	10.66	31.8
40	Porcelain rings	27.2	130.3	71.6	10.8	33.4

the yields of liquid, gaseous, and solid products were practically equal for the corresponding equal times of contact. A small fluctuation was observed both in the composition of the gas and of the tar.

Thus, porcelain as a filler has no influence upon the condensation of acetylene, but the filling of the tube with this added substance slightly improves the conditions of heat exchange, and this decreases the danger of local overheating and the decomposition of acetylene connected with this.

Silical Gel and Activated Charcoal as Added Substances

To fill the reaction tube we used well dried silica gel, the sizes of the separate particles being 4-5 m/m in cross-section. The free volume of the tube, filled with this added material, taking account of the porosity of the silica gel, amounted to about 75%, and this was taken into account in the determination of the duration of contact.

The experiments, carried out each time with fresh catalyst, showed (Table 3), that the yield of condensate not only did not increase, as has been indicated in the literature [2,10], but was appreciably decreased. Thus, at 700° and a duration of contact of 35.2 seconds, a total of 16.9% by weight of condensate was formed from the original acetylene. Under these conditions, in the case of a filler of porcelain rings, the yield of condensate amounted to more than 65% by weight of the original acetylene.

Neither a decrease in time of contact at a constant temperature of 700° (experiments Nos. 19, 20, 21, 22) nor a decrease in the temperature was able to increase the yield to the previous level.

The same picture was obtained with activated charcoal. We must point out the high degree of conversion of acetylene during this process. Thus, at 600°, up to 90% of the acetylene was decomposed, and at 700°, all the acetylene reacted.

If we add the yields of gas and of condensate it appears that in experiment 22, for example, the gas formed was 50.56% and the condensate 9.65% by weight of the gas used up, i.e., the total is considerably less than the original amount of gas.

The remaining 39.79% must obviously be sought in the carbon deposited in the form of coke or soot in the reaction tube. However, a total of about 3 g, or 4%, of coke was obtained, while the weight of the silica gel increased by 33.54 g, which amounted to 34.5% of the weight of the original gas, or 65.5% of the weight of the acetylene used up. Consequently, a large part of the acetylene was converted into products which underwent further condensation, and were deposited in

TABLE 3

Expt. No.	Temp. (in °)	Time of contact (in seconds)	Gas passed through (l) (0 760)	Yield of gas (in % of original gas)	Yield of condensate		Yield of carbon and gain in weight of filler		Degree of conversion of acetylene (in %)
					in % of original gas	in % of acetylene	in % of original gas	in % of acetylene	
16	500	10.7	200	83.40	10.91	19.0	3.82	6.67	56.0
17	600	9.9	184	71.00	13.62	20.8	12.48	21.80	81.5
18	650	9.4	227	63.60	14.37	25.0	19.32	33.80	89.4
19	700	5.86	233	63.50	20.6	34.8	13.87	24.20	81.4
20	700	8.6	218	55.00	22.1	38.6	18.90	33.0	100
21	700	17.52	184.5	52.5	13.3	23.4	31.10	54.50	100
22	700	35.2	133	50.60	9.65	16.9	37.50	65.50	100

the pores of the silica gel. Therefore, it was to be expected that as the accumulation of heavy condensation products took place in the pores of the silica gel, its porosity would diminish until there was complete plugging of all the pores. Then the influence of such a silica gel or activated charcoal on the condensation should not in any way differ from such relatively non-porous substances as porcelain, clay, glass, etc. This assumption was completely confirmed by experiments in which the same silica gel was used for a long time, with removal only for the periodic determination of its gain in weight.

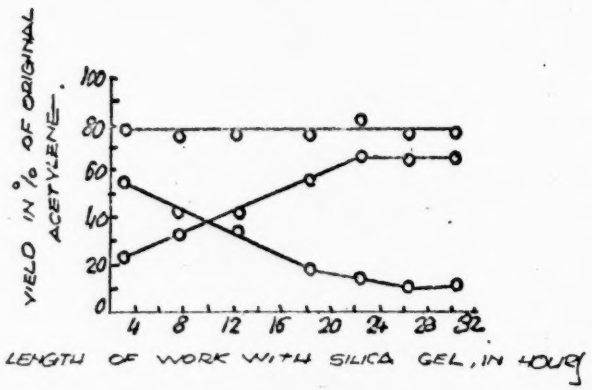

Fig. 2. Relation between yield of products of pyrolysis and duration of the operation with silica gel.

1) Liquid condensate; 2) condensation products deposited in pores of silica gel; 3) total of products of pyrolysis.

As can be seen from these experiments, carried out at 7000° and duration of contact of 17.5 seconds (Fig. 2), with an increase in the time of presence of the silica gel in the reaction tube, the yield of liquid condensate increased continuously, and after 22.5 hours reached 67% by weight of the original acetylene, and remained on this level from then on. The amount of heavy condensation products formed, and precipitated in the pores of the silica gel, on the other hand, in proportion as the yield of liquid products increased, decreased continuously from 54% at the beginning of the experiment to 12% after 23 hours. Upon further passage of acetylene, the yield of heavy condensation products was little changed and amounted to 10-11% by weight of the acetylene passed through.

Thus, in the initial stages of pyrolysis in the presence of porous fillers, a large part of the acetylene was converted into heavy condensation products and deposited in the pores of the filler, gradually completely plugging them. After the filling of all the pores, the yield and composition of all the products of pyrolysis stabilized in time and did not differ from the yield and composition of the products formed in an unfilled tube and in the presence of added porcelain

(Table 2). The crust of carbon which was deposited on the surface of the filler grew continuously as the amount of acetylene passed through increased, thus diminishing the free volume of the reaction space and consequently the time of contact. Upon sufficient duration of the experiment, this became less than the minimal time needed (12 seconds) for the maximum conversion of acetylene into liquid products. Finally, it approached the moment of complete filling of the reaction tube.

Taking these facts into account, it is not difficult to explain why the yield of condensate begins to fall after the optimal conditions of "preheating" of the silica gel are attained, and why the yield of condensate is again reduced if CO_2 [9] or water vapor [11] are passed for some time through the tube containing the silica gel. We are not dealing here with the poisoning of the hypothetical catalyst, that is, the film of carbon on the silica gel, and its regeneration, as Fischer has proposed [9], but with simple reactions of the oxidation of carbon:

$$CO_2 + C \rightleftharpoons 2CO,$$

$$H_2O + C \rightleftharpoons CO + H_2,$$

$$2H_2O + C \rightleftharpoons CO_2 + 2H_2,$$

as a result, the carbon in the form of CO and CO_2 leaves the reaction zone together with the gaseous products and by virtue of that fact the active lattice is increased. Carbon monoxide has been detected in the gases from pyrolysis both by Fischer [9] and by Berl [11] and their coauthors.

In conclusion, it appears to us in place to emphasize here that in the experiments of Zelinsky [2], the same activated charcoal served as a filler for a period of 40 hours, and that Lozovoi [10], repeating the experiments of Zelinsky, worked throughout with the same charcoal, without renewing it. Thus the activated charcoals in the experiments of Zelinsky and those of Lozovoi were already not porous substances.

During the pyrolysis of acetylene we collected 713 g of liquid condensate, from which we obtained and accurately determined: benzene, in a yield of 30.4%; toluene, in a yield of 5.5%; naphthalene, in a yield of 8.05%; and styrene, less than 1% by weight of the condensate.

SUMMARY

1. The pyrolysis of acetylene is accompanied by the formation of heavy condensation products which deposit on the surface of the reaction vessel as a carbon containing mass. This carbon is not a catalyst of the condensation of acetylene, but is an inevitable product of a number of transformations of acetylene.

2. Porous materials with strongly developed surfaces, like charcoal and silica gel, in the initial stages of pyrolysis favor the formation of heavy condensation products, which deposit in the pores of these materials.

After the pores are filled, and this takes from 10 to 20 hours, the action of the silica gel and the activated charcoal does not differ from the action of such fillers as porcelain, clay, and glass, whose roles are concerned only with improving the conditions of heat exchange.

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THE POLYMERIZATION OF VINYL FORMATE

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The esters of vinyl alcohol, which are easily obtained from organic acids and acetylene by liquid and vapor phase methods, are of great interest in connection with their tendency easily to undergo polymerization into very high molecular weight compounds. However, up to the present time, only vinyl acetate has been subjected to scientific investigation, as the original substance for the synthesis of a number of polymers. There are only brief indications in the patent literature concerning the polymerization of the remaining esters of vinyl alcohol. However, a number of these esters can be easily prepared, and easily polymerized just like vinyl acetate with the formation of high molecular weight polymers. In addition, they exhibit several peculiarities which are connected with the presence of other acyl radicals in them, and in this respect the simplest representative of this series, vinyl formate, deserves special attention.

This ester was first obtained by Zalkind, Ayzikovich, Vovsi and Ivanov [1] by passing acetylene through anhydrous formic acid saturated with boron fluoride and containing mercuric phosphate. The vinyl formate was then isolated in the form of an easily mobile liquid, which distilled from 50 to 54°, and was easily decomposed with water with the formation of aldehyde, and was transformed in the presence of benzoyl peroxide, after 12 to 15 days at ordinary temperature, into a solid, transparent polymer.

Later, Ushakov, Rostovsky, and Arbuzova [5] found that vinyl formate could also be obtained by a vapor phase method, namely, by passing a mixture of acetylene and formic acid at 185-190° over zinc acetate, carried on activated charcoal. The crude reaction product contained acetylene, formic acid, and about 5% of acetaldehyde, and was purified by rectification, which gave an ester with b.p. 46-46.5° and d_{20}^{20} 0.9592.

Upon heating with benzoyl peroxide, and even upon long standing without it, the ester was transformed into a solid, vitreous polymer, which was soluble in acetone and chloroform, but, in contrast to polyvinyl acetate, did not dissolve in alcohol, benzene, carbon tetrachloride, or ethyl acetate, and upon boiling with water was easily saponified to give polyvinyl alcohol.

On the other hand, Ushakov, Gavurina, and Chekhovskaya [3], also obtained polyvinylformate (PVF) by starting with polyvinyl alcohol (PVA). Under specific conditions, they were able to carry out the transformations PVA $\longrightarrow$ PVF $\longrightarrow$ PVA without changing the viscosity of the original alcohol, i.e., retaining the previous degree of polymerization. This permitted them to compute, indirectly, the value of K_m in the formula $\eta_{sp.} = K_m cM$, for polyvinyl formate, by multiplying

the ratio of the value of the viscosity of polyvinyl formate (0.031) to the value of the viscosity of polyvinyl alcohol (0.064) by the constant K_m of the latter polymer, which equaled $0.68 \cdot 10^{-4}$. The value of K_m for polyvinyl formate was thus equal to $0.33 \cdot 10^{-4}$.

With regard to the question of the polymerization of vinyl formate, except for the brief data indicated above, there exists in the literature no information on the course of this reaction and on the influence of the various factors on the properties of the polymers obtained. We therefore undertook the present investigation, which had for its purpose the study of the polymerization of vinyl formate in a more detailed manner, and in particular the investigation of the influence on the course of the process and on the molecular weight of the polymeric reaction products of solvents, peroxides, acetaldehyde, and the oxygen of the air, as well as an explanation of the degree to which the results of our observations are in accord with the modern theories of chain polymerization reactions. In all this, for the determination of the molecular weight of the polymers, we might have been able to utilize a viscosimetric method, if the relationship between the viscosity and the molecular weight of the polyvinyl formate had been accurately determined. However, we did not consider it possible to utilize for this purpose the equation $\eta_{sp.} = K_m c \cdot M$ where K_m equals $0.33 \cdot 10^{-4}$, in accordance with the author mentioned above, inasmuch as it was long ago shown that this equation is not applicable to the majority of linear polymers and in particular to the polyvinyl acetates, as K_m does not remain constant with a change in M.

As Wagner has shown, in the case of polyvinyl acetates, it has been necessary to substitute the equation $[\eta] = KM^a$, where $[\eta]$ is the so-called characteristic viscosity [2], equal to the listed viscosity $\eta_{sp.}/c$ at concentrations close to zero, and K and a are constants equal for the polymer fractions to $1.88 \cdot 10^{-4}$ and 0.69. But inasmuch as the values of these constants for polyvinyl formates are still not known, and could not be determined by us for lack of an osmometer, we were limited to the determination of the characteristic viscosity of our polymers in acetone. $\eta_{sp.}/c$, as is known, changes in the region of low concentrations linearly with the concentration in accord with the formula $\eta_{sp.}/c = [\eta] + K[\eta]^2 c$, which makes it possible to determine $[\eta]$ graphically, starting with several determinations of $\eta_{sp.}/c$ at different concentrations. As can be seen from Fig. 1, we also observed a rectilinear relationship between $\eta_{sp.}/c$ and c in the case of solutions of polyvinyl formates in acetone at concentrations from 0.2 to 0.8 g of polymer in 100 ml of solvent, and this made it possible to compute for each polymer the value of $[\eta]$ by a graphic method for the measurement of sections cut off by straight lines, expressing the relationship between $\eta_{sp.}/c$ and c by their intersection with the axis of ordinates.

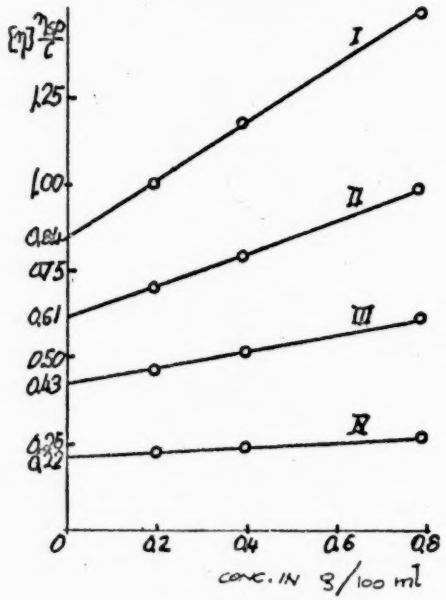

Fig. 1. Relationship between $\eta_{sp.}/c$ and c for the polymerization products of VF in the presence of acetone with 0.1% PB.

I) 0%; II) 10%; III) 20%; IV) 40% acetone in mixture

The values of the characteristic viscosity which we found, in the absence of data on the values of the constants K and a for polyvinyl formates in acetone, still did not make it possible to compute the molecular weight of the polymers we had obtained. But as they are closely related to the latter, they give an idea of the changes in the lengths of chain of the polymers under the influence of changes in the conditions of polymerization, and as will be shown below, the nature of the relationship between the values of $[\eta]$ and the concentrations of the initiator and modifier remain the same as is predicted by the theory for the relationship between the molecular weight and these factors.

EXPERIMENTAL

The vinyl formate which we used in our work was obtained by a vapor phase method and was purified from aldehyde and impurities by rectification in a column 1 m high, filled with pieces of glass tubing. The fraction boiling within the limits 45-46° was selected. However, when this fraction was polymerized, comparatively low molecular weight polymers were obtained, and no clear relationship was observed between the viscosity of the latter and the concentration of the catalyst, the dilution, and the other factors. This is to be explained by the insufficiency of the degree of purity of the monomer. But after a second, more careful rectification with the selection of a fraction boiling within a range of 0.1 to 0.2°, polymers were obtained which were found to have much higher viscosity, the latter changing in the expected directions according to rule as the indicated factors changed, and it was possible to consider the monomer fairly well freed from impurities.

TABLE 1

Relationship between boiling point of the vinyl formate and the pressure

Pressure of mercury column, in mm	Boiling point (°)
749	45.4-45.6
758	45.6-45.8
767	45.8-46.0
773	46.0-46.2

As the boiling point of the pure vinyl formate changed appreciably with a change in the barometric reading, we list in Table 1 the boiling points of vinyl formate found by us at different pressures.

The polymerization of pure vinyl formate, and the influence upon it of acetaldehyde and solvents

It is known that pure vinyl acetate, in the absence of oxygen, polymerizes extremely slowly. For example, at 140°, after 8 days, it forms only 2% of polymer, while in the presence of oxygen it polymerizes completely under the same conditions after a day. According to the data of Kezbertson, Dzhi, and Rideal [6], this is to be explained by the fact that in the presence of traces of moisture and alkali, vinyl acetate undergoes hydrolysis, being transformed into acetic acid and acetaldehyde. The latter, reacting with oxygen, gives a peroxide, which also catalyzes the polymerization of the monomer. Therefore, the pure vinyl acetate, which does not contain aldehyde, does not polymerize at 100° even in the presence of air, while vinyl acetate which contains acetaldehyde polymerizes only in the presence of oxygen.

On the other hand, it is known that the addition of insignificant amounts of acetaldehyde to vinyl acetate strongly lowers the viscosity of the polymers obtained [7]. Similar phenomena have also been observed by us in the polymerization of vinyl formate.

Thus, vinyl formate insufficiently purified by rectification, or the pure monomer containing aldehyde, in the presence of air slowly polymerizes, and is

converted, for example, in the presence of 1% of aldehyde at 55° after 7 days into a thick mass, from which the polymer may be separated by precipitation with alcohol. But upon heating the same mixture in an atmosphere of carbon dioxide, no polymerization is observed.

Similar phenomena take place also during the polymerization of pure vinyl formate in the presence of moisture, as the latter easily hydrolyzes the monomer, resulting in the formation of acetaldehyde and formic acid. Therefore, during the polymerization of vinyl formate it is necessary to use a carefully dried vessel and freshly distilled monomer under conditions which will prevent the penetration of moisture into the vessel from without during the process of polymerization.

In order to explain the influence of the acetaldehyde content of the original monomer on the internal viscosity of the polymers obtained, we carried out several experiments on the polymerization of vinyl formate at 55° in the presence of 0.1% benzoyl peroxide (PB), 25% of acetone, and different amounts of aldehyde. We thus obtained the following data, from which it is clear that the introduction into the monomer of 1% of aldehyde lowers the viscosity of the polymer obtained under these conditions to approximately two-thirds its value.

Percent aldehyde	0	0.075	0.5	1
$[\eta]$	0.32	0.31	0.26	0.23

In a similar way, but to a much lower degree, the presence in the monomer of a solvent of polyvinyl formate, such as acetone, formic acid, and chloroform, lowers the molecular weight of the polymers. These solvents were added to the monomer to the amount of 25%, the polymerization taking place at 55° in the presence of 0.1% of benzoyl peroxide, and polymers with the following viscosity were obtained:

Solvent:	None	Acetone	Formic acid	Chloroform
$[\eta]$	0.66	0.31	0.30	0.14

A similar action of solvents has been observed by many investigators in the case of other monomers as well.

Thus, for example, Ushakov and Faynshtein [8] found that polyvinyl acetates obtained in the presence of toluene and 1% of PB were little more than half as viscous as those formed in the presence of benzene or ethyl acetate with the same ratios of monomer and solvent (1:1), and Ushakov and Markov [9] showed that the viscosity of these polymers was considerably lowered as the content of solvent in the original mixture increased.

On the other hand, Medvedev [10], in an investigation of the kinetics of the polymerization of vinyl acetate in benzene solution, showed that one of the chief factors which determined the viscosity and the molecular weight of the polymers formed was the transmission of the chain by the molecules of the solvent.

Mayo [11] also arrived at the same conclusion, showing that in the case of transmission of the chain there is a linear relationship between the value of the reciprocal of the degree of polymerization (1/P) and the initial molar ratio of solvent to monomer [S]/[M], so that:

$$1/P - 1/P_0 = C\frac{[S]}{[M]},$$

where P_0 is the degree of polymerization of the polymer obtained in the absence of a solvent, and C is the constant for the transfer of the chain, equal to the ratio between the velocity constants of the reaction for the transfer of the chain and the reaction for the growth of the chain. This constant characterizes the tendency of the given solvent to lower the molecular weight of the product

and the monomer. For example, during polymerization in the presence of benzene and its homologs at 100°, the value of C varies from $0.31 \cdot 10^{-4}$ for benzene to $3.35 \cdot 10^{-4}$ for diethylbenzene.

During the polymerization of vinyl formate at 55° in the presence of acetone and 0.1% of benzoyl peroxide we also observed the gradual lowering of the viscosity of the polymers obtained as the content of solvent in the original mixture with the monomer increased.

TABLE 2

The viscosity of polyvinyl formates obtained in the presence of acetone containing 0.1% PB at 55°

Amount of acetone (% of mixture)	(moles/ mole VF)	Characteristic viscosity of polymer [η]	$\frac{1}{[\eta]}$
0	0	0.840	1.19
10	0.137	0.615	1.69
20	0.310	0.430	2.30
40	0.830	0.215	4.60

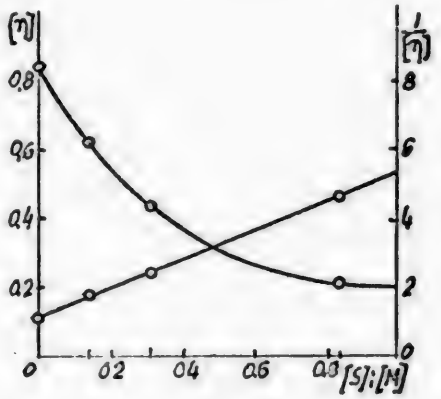

Fig. 2. Influence of the content of acetone in the original mixture on the viscosity of polyvinyl formates.

As can be seen from Table 2 and Fig. 2, the viscosity of polyvinyl formates is at first rapidly, and then slowly, lowered as the concentration of acetone increases, and at 40% of acetone in the mixture attains a value of the viscosity one fourth that of the polymer obtained in the absence of acetone. But the value of $1/[\eta]$ grows almost rectilinearly with an increase in the concentration of acetone, as was to be expected in the case of transmission of the chains by the molecules of acetone.

The influence of benzoyl peroxide on the polymerization of vinyl formate

As is known, benzoyl peroxide, which decomposes into radicals, has the ability to initiate the polymerization of vinyl compounds, an increase in its concentration (c) resulting, in addition to an increase in the velocity of polymerization ($V_{tot.}$), in a decrease in the degree of polymerization (P) of the polymer obtained, in accordance with the equations

$$V_{tot.} = K\sqrt{c} \quad \text{and} \quad P\sqrt{c} = K',$$

deduced by Schultz in an investigation of the polymerization of styrene [12].

As Kamenskaya and Medvedev [10] have shown, and also Kezbertson, Dzhi, and Rideal [8], similar relationships have been observed between the total velocity of the reaction and the degree of polymerization (or the viscosity of the polymer, which increases with the increase in P) and the concentration of benzoyl peroxide in the polymerization of vinyl acetate as well.

Therefore it was of interest to clarify whether the benzoyl peroxide also influenced the polymerization of the vinyl formate. With this objective in mind, we heated solutions of from 0.04 to 1.6% benzoyl peroxide in vinyl formate as well as the pure monomer, in sealed tubes (containing air) at 55°, until the contents of the tubes hardened, and then determined the viscosity of the precipitated

polymers in acetone.

The results obtained by us are presented in Table 3 and in Figs. 3 and 4.

TABLE 3

The influence of benzoyl peroxide on the polymerization of vinyl formate

Expt. No.	PV (C, %)	$\sqrt{C}$	Time for hardening, hours	[η]	$\frac{1}{[\eta]}$
1	0	0	175	0.45	–
2	0.04	0.200	14	0.90	1.10
3	0.10	0.316	8	0.70	1.42
4	0.40	0.630	5	0.43	2.30
5	0.80	0.895	3	0.30	3.30
6	1.60	1.250	2	0.20	5.00

It can be seen from Fig. 3 that in the absence of benzoyl peroxide (but in the presence of small amounts of air) vinyl formate is polymerized only after 7 days, being transformed into a comparatively low-viscosity polymer. But in the presence of 0.04% of PB, the time of polymerization is decreased to 14 hours, and with an increase of the percentage of PB to 1.6%, is decreased to 2 hours. On the other hand, an increase in the content of peroxide in the monomer from 0.04 to 1.6% results in a gradual lowering of the viscosity of the polymers from 0.9 to 0.2 (see curve in Fig. 3). But as Fig. 4 shows, there is an almost linear relationship between the values of $\sqrt{\%\ \text{PB}}$ and $1/[\eta]$, as was to be expected from the results cited above on the investigation of the kinetics of polymerization of vinyl acetate and styrene.

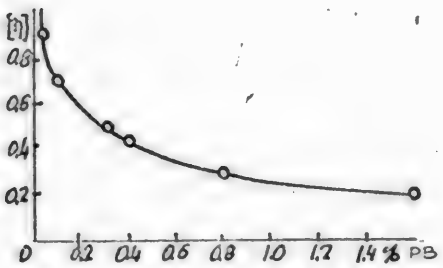

Fig. 3. Relationship between [η] of polymer and concentration of PB.

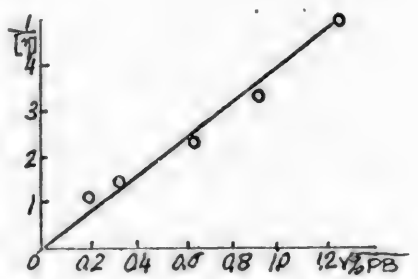

Fig. 4. Relationship between $1/[\eta]$ and $\sqrt{\%\ \text{PB}}$.

The investigation of the composition of the polymerization products of styrene and other compounds in the presence of organic peroxides has also made it possible to explain the mechanism of the initiation of polymerization by peroxides.

As Medvedev [10] has shown, polystyrene obtained in the presence of benzoyl peroxide, even after numerous reprecipitations by alcohol from ether solution, shows the presence of the C_6H_5COO group, which is split off in the form of benzoic acid upon saponification of the polymer.

The author cited has explained this by the fact that benzoyl peroxide splits up, in the presence of the monomer, into radicals

$$(C_6H_5\text{-}COO)_2 \longrightarrow C_6H_5\text{-}COO\cdot + CO_2 + C_6H_5\cdot,$$

which initiate the polymerization of the monomer because of the addition of the radicals to the molecules of monomer, with the formation of active centers

$PhCOO-CH_2CHX\cdot$ or $PhCH_2CHX\cdot$. The growth of the chains then takes place by the addition of molecules of the monomer to the active center, and the formation of a polymer by the recombination of the growing chains:

$$RA_n\cdot + R_1A_m\cdot \longrightarrow RA_{n+m}R_1$$

or by the transfer of the reaction chain:

$$RA_n\cdot + LH \longrightarrow RA_nH + L\cdot,$$

where A is a molecule of monomer, and R and R_1 are radicals formed by the decomposition of the peroxide.

This mechanism has found confirmation in later investigations by other authors, who have studied the polymerization of styrene in the presence of halogen-containing peroxides. They have found that the polymerization products contain from 0.5 to 2 fragments of peroxide per 1 molecule of polymer. But the polymers of the vinyl esters have not been investigated in this respect.

Therefore we conducted several experiments on the polymerization of vinyl formate in the presence of p-bromobenzoyl and monochloroacetyl peroxides, and determined the halogen content in the polymers obtained, after careful purification (Tables 4 and 5).

TABLE 4

Determination of halogen in polymer (Carius)

Expt. No.	Sample (g)	Obtained (g)	Bromine in polymer, %	Note
1	0.1336	0.0021	0.670	Analyses 3 and 4 refer to a polymer which was reprecipitated twice more from acetone with alcohol
2	0.1359	0.0022	0.690	
3	0.1792	0.0033	0.78	
4	0.1642	0.0027	0.75	

TABLE 5

Determination of chlorine in polymer (Carius)

Expt. No.	Sample (g)	Obtained (g)	Chlorine found, %	Note
1	0.1662	0.0065	0.98	Polymers 2 and 3 were reprecipitated twice more from acetone with alcohol
2	0.1470	0.0050	0.85	
3	0.1638	0.0053	0.80	

In the experiments with p-bromobenzoyl peroxide, a mixture of 6 g of vinyl formate, 48 g of acetone, and 1.5 g of peroxide was heated till there was almost complete decomposition of the peroxide. The solution was then cooled, crystals of p-bromobenzoic acid precipitating out of it. These were filtered off. Then the polymer was obtained from the filtrate by dilution with alcohol. It was further purified from low molecular weight impurities by numerous reprecipitations from acetone with alcohol, washed with alcohol, and dried to constant weight in vacuum at 55°.

It was a white powder which readily dissolved in acetone with the formation of low-viscosity solutions ($[\eta] = 0.007$).

If we assume that the molecule of polymer contains on an average only 1 atom of bromine (in the form of bromophenyl, or the radical BrC_6H_4COO), then the

molecular weight of the polymer which contains 0.7% of bromine must amount to about 11,000, and its degree of polymerization to 150.

The polymerization of vinyl formates in the presence of chloroacetyl peroxide took place in the following manner. A solution of 3 g of monomer and 0.3 g of peroxide in 10 ml of acetone was heated to 55° for 28 hours, after which time it gave only a weak reaction for peroxide. Upon the addition to the resultant solution of an equal volume of alcohol, about 1.5 g of polymer precipitated out. This was purified by numerous reprecipitations from acetone with alcohol. There was thus obtained a white powder, which was carefully washed with alcohol and dried to constant weight in a vacuum at 55°. The characteristic viscosity of the polymer in acetone amounted to 0.0025.

In the presence of 1% of chlorine in the samples investigated and of 1 atom of halogen per molecule of polymer, the molecular weight of the latter must have amounted to about 3600, which corresponded to a degree of polymerization of 50.

The influence of air on the polymerization of vinyl formate

As is known, the oxygen of the air can considerably influence the polymerization of unsaturated compounds. At first its absorption by the monomer is observed, and a retardation of polymerization, followed by an acceleration of the latter which results from the formation of peroxides. Thus, in the case of the photopolymerization of vinyl acetate, Menie and Vassner found that the induction period (PI) in the presence of nitrogen, air, and oxygen was 3, 10, and 19 hours respectively, and that during this period the absorption of oxygen took place.

On the other hand, it has been found that polyvinyl acetates obtained in the presence of air by photolytic or thermal polymerization have a considerably lower molecular weight than those formed in the absence of oxygen. Therefore, it was of interest to study the influence of air on the polymerization of vinyl formate also.

With this purpose, small amounts of the monomer were placed in 20 or 30 accurately weighed ampoules (capacity about 1 ml each), the monomer containing 0.1% of benzoyl peroxide as well as (in certain experiments) acetone. The ampoules were then sealed, again weighed, and placed in a water thermostat, whose temperature was automatically maintained at 55°.

In order to determine the percent of transformation, 2 or 3 ampoules were removed from the thermostat after definite intermediate periods and broken with a glass stirring rod under 10 ml of acetone. The polymer then went into solution on heating, and was then precipitated with 20 ml of alcohol, filtered off, and dried to constant weight.

In the experiments with air, the extent to which the ampoules were filled varied from 50 to 75%. In the other experiments, the air was first displaced with dry carbon dioxide, the monomer then placed inside, and the ampoule sealed off. Finally, in the first series of experiments, the ampoules were evacuated by means of a water-jet pump, as a result of which the liquid inside them began to boil. Then, after the air had been displaced by vapors of the monomer, the ampoules were sealed under conditions which involved the continued distillation of the monomer from them.

The results of various experiments are shown in Table 6 and in Fig. 5.

From Fig. 5 it is clear that an induction period (in the course of which the velocity of polymerization greatly increases) is observed in all cases, and that at the end of the PI a large part of the monomer polymerized with constant velocity, equal to 15% or 16% per hour in experiments 2 to 5 and 5% per hour in

TABLE 6

Velocity of polymerization of vinyl formate (VF) at 55° in the presence of 0.1% PB

Expt. No.	VF in liquid phase, %	Gas phase: Composition	Gas phase: Volume (%)	Percent of polymer formed after: (hours) 1	2	4	8	12	24	32	PI (in hours)
1	80	air	50	–	–	–	3.7	14.8	73 8	86.6	10
2	80	air	40	–	–	6.3	26.4	78.4	89.3	89.5	6
3	80	air	24	–	–	9.9	60.0	84.5	90.8	91.2	3.8
4	80	CO_2	25	3.3	7.4	30.9	81.8	91.0	–	92.6	2
5	100	CO_2	25	5.8	9.9	50.0	90.0	92.0	–	–	1
6	100	vacuum	25	4.5	6.7	52.0	–	–	–	91	1

Experiment 1, with the greatest content of air in the ampoules.

Thus, in the latter case, the oxygen of the air acted not only as an inhibitor but also as a retarder of polymerization. The size of the induction period found graphically by intersection with the axis of abscissas of the straight line representing the fundamental velocity of polymerization varied in Experiments 1 to 5 from 10 hours to 1 hour (Fig. 5 and Table 7) and was especially great in the experiments on the polymerization of vinyl formate in the presence of air (Experiments 1 to 3). It increased almost proportionally to the ratio of the content of oxygen in the ampoules to the volume of monomer. This is clear from Table 7, and coincides with the results of other authors [1] with regard to the influence of oxygen on the length of the induction period, as observed during the polymerization of styrene.

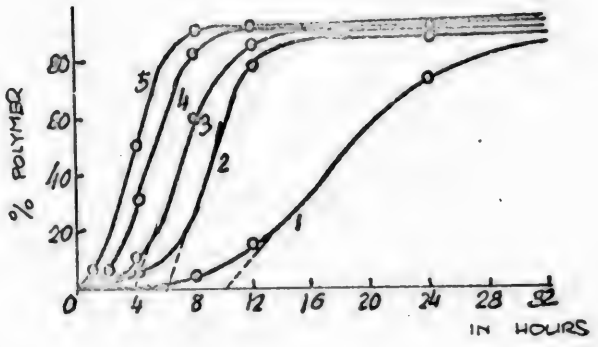

Fig. 5. The velocity of polymerization of vinyl formate.

Curves 1 3: 80 VF plus 20 acetone in the presence of air, with ampoule 50, 60 and 75% filled: 4, same, in presence of carbon dioxide; 5, 100% VF under CO_2, in vacuum.

TABLE 7

No. of Experiment	1	2	3
Ratio of volume of air to volume of monomer	1	0.67	0.33
Induction period (hours)	10	6.00	3.60
PI: volume of air	10	9.00	11.00
Oxygen content (in ml per 1 g of vinyl formate)	0.22	0.15	0.08
ml of O_2 that had to be absorbed during PI per 1 g of monomer	0.25	0.15	0.09

The cause of the delay in the polymerization of vinyl formate in the presence of air is obviously the reaction of the monomer with the oxygen of the air. Therefore it was of interest to cast light on whether there was absorption of oxygen by the monomer, and if there was absorption, on the speed with which it took place.

With this purpose in mind, we placed 15 g of pure monomer in an ampoule of 100 ml volume, filled with dry oxygen and connected by means of a ruber tube with a nitrometer containing oxygen and mercury. Over a period of two weeks we measured the level of the mercury in the nitrometer, taking into account also the pressure and the temperature, which throughout the entire experiment was close to room temperature.

This experiment showed that after 15 days, 13.3 ml of oxygen were absorbed under normal conditions, i.e., that the velocity of absorption of oxygen amounted to $9/(15 \cdot 24) = 0.025$ ml per hour per 1 g of monomer. This made it possible to compute how much oxygen must be absorbed during the induction period in Experiments 1 to 3 per 1 g of monomer if the absorption in these experiments took place with the same velocity, and to compare the volumes found with the volumes of oxygen which were present per 1 g of monomer in the sealed ampoules in these experiments when the ampoules were 75, 60, and 50% filled. As Table 6 shows, during the induction period, exactly the same amount of oxygen had to be absorbed in Experiments 1 to 3 as was present in the ampoules, or an amount which was very close to it.

Thus, it can be seen from all this that the velocity of polymerization of vinyl formate reaches a normal value only after the absorption of all the oxygen contained in the ampoule.

The formation of an insoluble granular polymer during the polymerization of vinyl formate

In studying the polymerization of pure vinyl formate in the absence of solvents, we noted that sometimes, after considerable thickening of the monomer with the formation of a viscous transparent vitreous mass, after the ampoules had been cooled to room temperature, there were present in them white, non-transparent inclusions in the form of fine grains, distributed both inside the vitreous reaction product and outside it, for example, in the narrow extension of the ampoule. These grains began to grow, and also increased in number, and after several dozen minutes, a considerable portion of the vitreous polymer had been transformed into a granular one. This transformation was accompanied by a vigorous evolution of heat in the ampoule. As a result, there was obtained a mixture of vitreous polymer with white non-transparent grains disseminated through it.

The phenomenon of the formation of a granular polymer was observed by us only in those cases when the pure freshly distilled monomer was subjected to polymerization in the absence of air (for instance, in evacuated ampoules, or in ampoules which had first been filled with carbon dioxide), or in the presence of very small amounts of it, as for example when the ampoules were more than 3/4 filled.

If the monomer was insufficiently pure or was kept for a long time in the presence of air, or if the conditions were such that the pure freshly distilled monomer was subjected to polymerization in the presence of acetone, or even if it was polymerized in the presence of air when the filling of the ampoules did not exceed 75%, no formation of a granular polymer was observed, and only the vitreous polymerization product was obtained.

The granular polymer differed sharply from the vitreous one in its behavior

with solvents: while the latter dissolved readily in acetone, chloroform, and formic acid, the granular polymer did not dissolve in these solvents even upon prolonged boiling, and it was not soluble in other solvents, such as dichloroethane, carbon tetrachloride, and acetic acid. Therefore it could be easily separated from the vitreous polymer by extracting the latter with acetone, the granular polymer remaining in the form of soft, swollen nodules, which upon drying gradually lost solvent and were converted into a solid, semitransparent mass.

It differed sharply from the vitreous polymer also in its behavior with weak acid solutions of alkali. Ordinary polyvinyl formate easily underwent saponification even by boiling water, with the formation of polyvinyl alcohol, which was soluble in water. But the granular polymer could be made to go into aqueous solution only after lengthy treatment (for a period of 3 or 4 days) with boiling aqueous alkali. This gave considerably less viscous solutions than in the case of the vitreous polymer.

Thus, for example, the saponification of the vitreous polyvinyl formate ($[\eta] = 0.1200$ in acetone) gave a polyvinyl alcohol with $[\eta] = 0.1068$ in water, while the granular polymer gave an alcohol with $[\eta] = 0.0622$.

The formation of white grains in the vitreous polymer under the conditions when it was cooled to room temperature, and the later growth of these grains and the increase in their number, accompanied by a fairly vigorous evolution of heat from the mass, was strongly reminiscent of slow crystallization. However, under the microscope, the granular polymer did not show any indications of crystalline form. Therefore, in order to shed light on the question as to whether the formation of the grains and their growth was a crystallization of the amorphous polymer, we undertook an X-ray investigation of the vitreous and granular polymers. However, both polymers gave the same roentgenograms, characterized by the presence of two diffuse rings of average sharpness, corresponding to identity periods of 5.3 and 3.35 A, and testifying to the amorphous character of both polymers and to the great similarity in structure of their chains. On the other hand, the insolubility of the granular polymer in organic solvents and the difficulty of its transformation into water-soluble polyvinyl alcohol during saponification indicated that it was a tri-dimensional polymer.

The formation of insoluble polymers which are capable of spontaneous growth in the presence of the monomer has, as is known, been repeatedly observed during the polymerization of divinyl and its derivatives. This phenomenon was first observed in 1901 by Kondakov [15] in the case of 2,3-dimethylbutadiene. Upon storage in the light in a sealed vessel, this hydrocarbon gradually was transformed into a white spongy mass, which filled the entire vessel and was insoluble in organic solvents.

The same phenomenon was later observed by S.V.Lebedev [16], who noted that it also took place in the dark, especially if the polymer was kept in unsealed vessels. It was characterized by the appearance of lumps, which gradually grew at the expense of the monomer until it completely used up the latter. The introduction of the already prepared spongy polymer into the monomer considerably accelerated this process.

A similar phenomenon was observed in the cases of isoprene and chloroprene. As Carothers [17] showed, the latter diene, under definite conditions, and especially under the influence of ultraviolet light, of various metals, or of the prepared polymer, was converted into an insoluble ω-polymer, which separated in the form of fine granules, these gradually growing into a voluminous porous mass which exerted considerable pressure on the walls of the flask and sometimes resulted in shattering the latter.

As Koblyansky and Piotrovsky [18] have shown, the formation of an insoluble

porous polymer also takes place during the polymerization of divinyl at 40 to 60° in the presence of air.

The spongy polymers are capable of growing not only in the liquid of the original monomer but also in its vapors, as well as in monomers of different composition [19]. For example, the insoluble polymer obtained from divinyl can grow in dimethylbutadiene and also in styrene. But in the latter the polymer gradually loses its activity. The spontaneous growth of the spongy polymers of dienes is apparently related to the presence in them of a great number of allyl groups, which easily undergo autoxidation, with the subsequent splitting off of oxygen from CH_2 groups and the formation of numerous active centers, to which addition of the molecules of the monomer also takes place, resulting in the growth of the insoluble polymer [19].

Thus, the reaction under consideration is apparently closely related to the diene nature of the original monomers and to the autoxidation of their insoluble polymers, and therefore cannot be the cause for the formation of the insoluble polyvinyl formates observed in the absence of air.

As for the monovinyl compounds, the formation of insoluble polymers is sometimes observed during their polymerization. These, however, have not shown a tendency to spontaneous growth in the presence of the monomer.

Thus, Blaikie and Crozier [7] noted that upon heating vinyl acetate with sodium perborate and acetic anhydride, the formation of a white insoluble polymer took place, after which the viscosity of the solution reached 100 cp. They also noted that solvents hindered the formation of this polymer. On the other hand, Kezbertson [8] observed the formation of an insoluble polymer during the latter stages of polymerization of vinyl acetate at 80° in the presence of benzoyl peroxide.

The cause of this, in the opinion of the author cited, is the branching of the chain, as a result of the reaction of the growing polymer with "dead" polymer. That this reaction can, in fact, take place was recently shown by an experiment on the polymerization of chlorostyrene in the presence of polymethylmethacrylate dissolved in it. A halogen-containing branched polymer [20] was obtained, apparently formed according to the mechanism:

$$\ldots CHXCH_2CHXCH_2CHXCH_2\ldots + R\cdot \rightarrow$$
$$\rightarrow \ldots CHXCH_2\dot{C}XCH_2CHXCH_2\ldots. + RH \qquad (a)$$

$$\ldots CHXCH_2\dot{C}XCH_2CHXCH_2\ldots + nCH_2{-}CHY \rightarrow \ldots CHXCH_2CX\begin{matrix}CH_2CHXCH_2\ldots \\ (CH_2CHY)_n\cdot\end{matrix} \qquad (b)$$

where R· is the growing chlorostyrene polymer and X and Y are the radicals CH_3OCO- and ClC_6H_4-.

A reaction of this sort, which leads to the transfer of the chain from a growing polymer or from initial active centers to nonactive molecules of polymer, can also in the case of vinyl formate lead to the formation of a nongrowing polymer, in particular at the end of polymerization, when the concentration of polymer in the mixture and the viscosity of the latter reach considerable values. On the other hand, we cannot exclude the possibility of the same reaction of radicals formed from benzoyl peroxide and the monomer, with a polymer which is not growing but is swollen with the monomer. As a result of this, active centers can penetrate into the polymer, and at certain spots the addition of the molecules of monomer can take place, and the initially formed fine grains of polymer can grow in all directions. This process of branching must be hindered by the agents for transfer of the chain (this is utilized to prevent the formation of

insoluble rubbers during the polymerization of dienes) and this may possibly explain the nonformation of insoluble polyvinyl formates in the presence of acetone and other added substances, as well as in the presence of oxygen, which is, as has been indicated above, an inhibitor of the polymerization of vinyl formate, i.e., it is a substance which cuts down the formation of active centers.

The formation of the insoluble polyvinyl formate may possibly be explained also by the splitting off from the molecules of the soluble polymer of molecules of formic acid, with the formation in the polymer of active double bonds and with the subsequent "sewing together" of macromolecules at the positions of these bonds.

However, this mechanism of reaction seems to us hardly probable, in particular if we take account of the fact that the formation of the granular polymer is observed at low temperatures, close to room temperatures, and is accompanied by a considerable evolution of heat.

SUMMARY

1. Insufficiently purified vinyl formate, obtained by a vapor phase method, gives upon polymerization a low viscosity polymer, which results from the presence of aldehyde impurity. The latter can considerably lower the molecular weight of the polymers obtained from pure vinyl formate.

2. Pure vinyl formate, in the absence of aldehyde, moisture, and initiators, but in the presence of air, as well as vinyl formate with added aldehyde in the absence of air, even after long heating gives only an insignificant amount of the low viscosity polymer. But in the presence of aldehyde and air, the monomer polymerizes even upon standing at ordinary temperature. This is explained by the formation of a peroxide from the aldehyde.

3. Benzoyl peroxide accelerates the polymerization of vinyl formate and lowers the molecular weight of the polymers obtained all the more the greater its amount in the original monomer. The lowering of the viscosity of the polymers obtained is also observed during the polymerization of vinyl formate in the presence of acetone, as a result of the transfer of the chain by the diluent.

4. In the polymerization of vinyl formate in the presence of p-bromobenzoyl peroxide and chloroacetyl peroxide, halogen-containing polymers are formed. This is explained by the initiation of polymerization by the cleavage products of the peroxides, which remain chemically bound to the polymer.

5. In the polymerization of pure vinyl formate in the presence of benzoyl peroxide and air, an induction period is observed. This increases in proportion to the ratio of the air volume to the volume of monomer, and during its course there takes place the absorption of the oxygen contained in the air.

6. In the polymerization of pure vinyl formate in the absence of diluents and air (or in the presence of small amounts of the latter) after the mixture has thickened considerably, the formation of insoluble white grains is observed. These gradually grow within the vitreous polymer with the evolution of heat, and give roentgenograms similar to those of the vitreous polymer, with two diffused rings, which indicate the amorphous nature of the polymer. This phenomenon can be explained by the formation of a three-dimensional polymer as a result of the reaction of the growing chains with the molecules of diene polymer.

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THE SYNTHESIS OF N-(1-NAPHTHYL-4-AZOBENZENE)-ETHYLENEDIAMINE, A REAGENT FOR PENICILLIN

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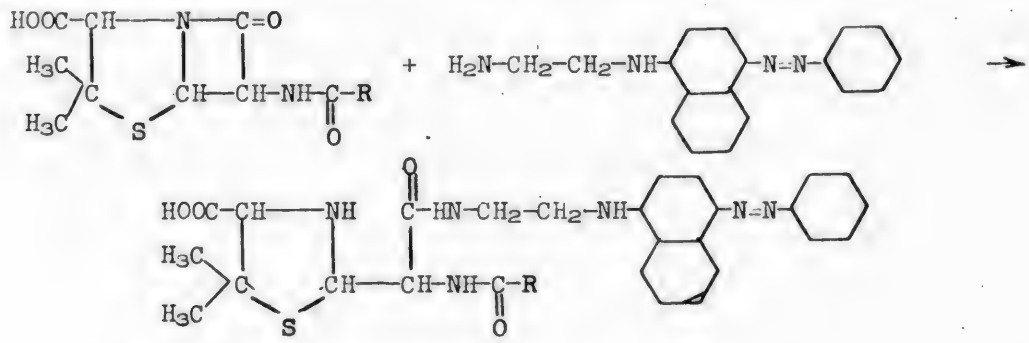
The discovery of the β-lactam structure of penicillin [1] made it possible to develop a chemical method for its determination. In 1946, Scudi [2], after testing a large number of amines, found that N-(1-naphthyl-4-azobenzene)-ethylenediamine was the most suitable reagent for penicillin.

This amine reacts with penicillin by condensing according to the following mechanism.



R indicates the radical of the different types of penicillin.

The colored condensation product can easily be extracted from the reaction mixture and determined quantitatively from the intensity of its color by means of a graduated photometer or an electrophotocolorimeter. Scudi also used this reaction as the basis of the colorimetric method he developed for the determination of penicillin.

Because of the relatively complicated nature of the synthesis of the dye, chiefly of the two intermediate products necessary for the preparation of the reagent, that is, β-bromoethylphthalimide and N-(1-naphthyl)-ethylenediamine dihydrochloride, the chemical method has not found wide application, despite a large number of advantages compared to the cumbersome biological methods, which require special conditions.

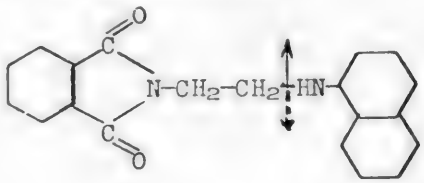
In our work, we made it our objective to simplify the synthesis of β-bromoethylphthalimide and N-(1-naphthyl)-ethylenediamine dihydrochloride and thus to make accessible also a simple method of preparation for the penicillin reagent.

The failure to have at our disposal several starting and intermediate products forced us to include the syntheses of the following compounds: dibromoethane,

phthalimide, β-bromoethylphthalimide, β-(1-naphthylamino)-ethylphthalimide, N-(1-naphthyl)-ethylenediamine dihydrochloride, the diazonium salt, and N-(1-naphthyl-4-azobenzene)-ethylenediamine.

EXPERIMENTAL

For the preparation of the amine we selected Gabriel's method [3]. However, we found that the unfavorable aspects of this synthesis were the following: the preparation of the potassium phthalimide and the splitting off of phthalic acid. In order to obtain potassium phthalimide it was necessary to have a large amount of absolute alcohol because of the low solubility of the phthalimide (5 g per 1 liter of water or per 100 ml of absolute alcohol upon boiling). In addition, it was seldom possible to obtain the pure compound in good yield. In our experiments, the hydrolysis of β-(1-naphthylamino)-ethylphthalimide took place with difficulty even with fuming HCl in sealed tubes at a temperature of 150-160°. The splitting off of the phthalic acid did not take place smoothly, and there was partial cleavage of the naphthylamine



A very impure preparation was obtained, which was purified with difficulty by means of the picrate. Our attempt to apply the Ing and Menske [4] modification to these reactions gave good results.

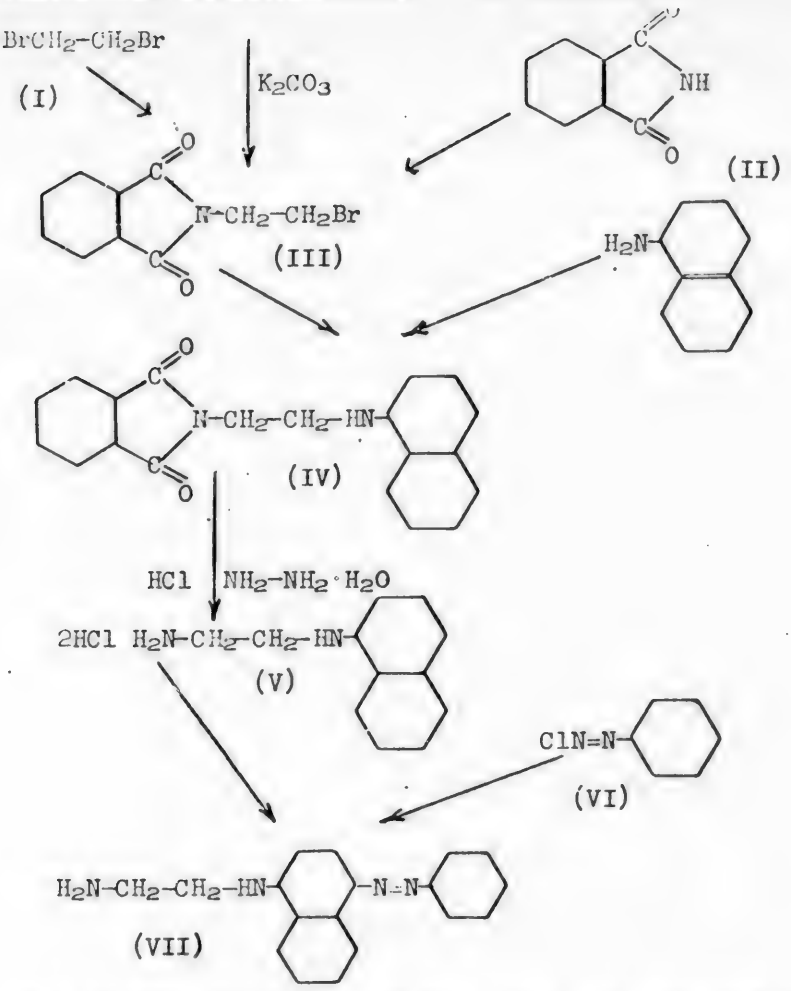
Thus, the entire course of the synthesis could be pictured as in the scheme (cf. page 2369).

Dibromoethane (I) was synthesized in the usual manner by the method of Gatterman; for the synthesis of β-bromoethylphthalimide we used the fraction boiling at 129-130°.

Phthalimide (II) was obtained from phthalic anhydride and ammonium carbonate.[4] The synthesis required a pure preparation, recrystallized from water.

β-bromoethylphthalimide (III). In a round-bottomed flask of 500 ml capacity, there was placed a mixture of 75 g of phthalimide and 37.5 g of anhydrous potassium carbonate, which had first been pulverized and mixed in a mortar. 250 g of dibromoethane was then added. The flask was fitted with an attachment for a mechanical stirrer and for two condensers. The flask and its contents were slowly heated on an oil bath, the contents of the flask being well stirred with the mechanical stirrer. Upon slow heating of the oil bath to 130-140°, the reaction mixture, which was at first very fluid, hardened. The mechanical stirrer was removed, and the heating continued for 6 to 8 hours more at a bath temperature of 170-180°. The hardened mass became fluid at the end of the heating, being similar in its appearance to a brown oil. The excess of dibromoethane was distilled off under vacuum at 10 to 20 mm, or steam distilled. The dibromoethane driven off was 130-140 g. The residual viscous mass (which hardened upon cooling) was washed 4 or 5 times with hot water to remove mineral salts. The residue in the flask was dissolved in 150 ml of alcohol by heating on the water bath for 30 to 40 minutes. The hot alcoholic solution was filtered on a Nutsch filter. Upon cooling, crystals precipitated from the alcoholic solution. They had a faint brown color. The yield was 100-120 g. These crystals were a mixture of β-bromoethylphthalimide and diphthalimidethane. Their separation took place in a Soxhlet apparatus with petroleum ether (boiling range 40-60°) over a period of 10 to 12

[4] Syntheses of Organic Compounds, Vol. 1.



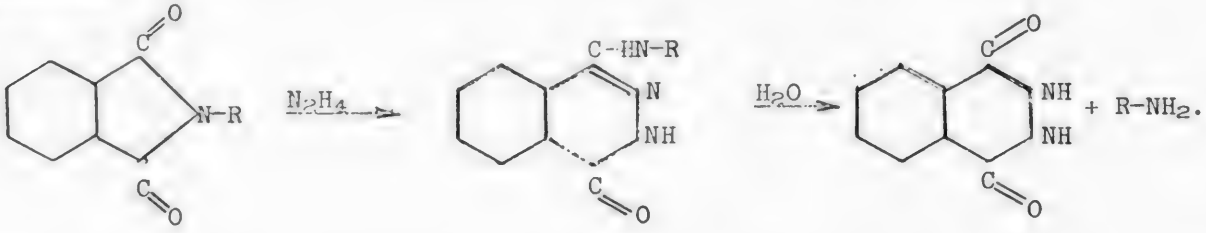
hours. Only the β-bromoethylphthalimide went into the petroleum ether. After recrystallization from hot 75% alcohol and decolorization with a small amount of animal charcoal, it was obtained in the form of colorless needle-shaped crystals with m.p. 82-83.5°. The yield was 60-70 g of pure β-bromoethylphthalimide. The residue left in the holder after the extraction with petroleum ether was transferred to a flask and heated with carbon disulfide for 2 hours. Not even traces of β-bromoethylphthalimide were observed in the solution.

N-(1-Naphthylamino)-ethylphthalimide. The synthesis of this compound was carried out basically by the method of Newman [5], with the use of the Bratton-Marshall modification [6]. A mixture of 40 g of β-bromoethylamine and 60 g of freshly recrystallized α-naphthylamine was carefully ground in a mortar, transferred to a flask, and slowly heated on an oil bath to 160°. The dark brown viscous mass that was formed was washed with a large amount of hot water (1000 ml) and then finally with 50 ml of warm alcohol. The residue in the flask was washed with hot alcohol. When the alcoholic solution cooled, the yellow amorphous precipitate was filtered off, dried, recrystallized from alcohol, and decolorized with a small amount (3 g) of animal charcoal. Golden-yellow crystals of β-(1-naphthylamino)-ethylphthalimide were obtained, with m.p. 158°. Yield 25-30 g.

Bratton and Marshall [6] recommend that the crude product be crystallized from glacial acetic acid. The golden-green crystals we obtained by this method had m.p. 163-165°. The yield by this method was one and a half times as great as when the recrystallization was from alcohol.

N-(1-Naphthyl)-ethylenediamine dihydrochloride (V). The preparation of this compound could be carried out by splitting off phthalic acid from β-(1-naphthylamino)-ethylphthalimide. For this purpose we tried out the usual method used in organic synthesis, hydrolysis by means of fuming HCl in sealed tubes at 150-160°, as well as a method based on the rapid distillation of the amine under vacuum (10 to 20 mm) from a carefully ground mixture of equal weights of dry NaOH and β-(1-naphthylamino)-ethylphthalimide. As both methods gave very unsatisfactory results, we next carried out the hydrolysis of β-(1-naphthylamino)-ethylphthalimide by the method of Ing and Menske [4].

The chemistry of this reaction has not been conclusively investigated. Ing and Menske suggested that this reaction took place according to the following mechanism:



A sample of 20 g of β-(1-naphthylamino)-ethylphthalimide was suspended in 200 ml of alcohol, and 6.5 g of 50% hydrazine hydrate was then added. The reaction mixture was boiled with a reflux condenser on a water bath for 3 hours. At the end of the first hour of heating, white flocs appeared in the solution. After 1.5 to 2 hours, the entire mass hardened. After 3 hours of heating of the reaction mixture, the white precipitate which had formed was subjected to hydrolysis by the addition of 100 ml of a 50% solution of HCl. The heating was continued for an additional hour, and the insoluble phthalyl hydrazide was then filtered off, and washed with water. The filtrate was concentrated by driving off about 150 ml of the alcohol. Upon cooling, crystals of phthalyl hydrazide again precipitated out. These were filtered off.

To the remaining filtrate there was added a concentrated solution of KOH until there was a definite alkaline reaction. The amine was extracted with dry ether. The ether extract was dried over solid KOH and transferred to a flask. After dry HCl had been passed into the ether solution of the amine, a white flocculent precipitate formed. This was the amine salt, N-(1-naphthyl)-ethylenediamine dihydrochloride.

The precipitate was collected on a filter, rapidly squeezed out between sheets of filter paper, and dried in a vacuum desiccator. The yield of crude product was 5 to 7 g. After recrystallization from 6 N HCl with activated charcoal, white crystals of N-(1-naphthyl)-ethylenediamine dihydrochloride were obtained, with m.p. 182-188°, (there was no constancy of the melting point). Even after several recrystallizations from 6 N HCl, the melting point remained unchanged. Upon substituting for the hydrazine hydrate an equivalent amount of hydrazine sulfate, with the addition of Na_2CO_3 and a small amount of water, the hydrolysis took place smoothly, and good yields of the crude product were obtained.

N-(1-Naphthyl-4-azobenzene)-ethylenediamine [2] (VII): A preliminary step for the synthesis of the reagent was the preparation of the diazonium salt (4). 5 g of freshly recrystallized aniline hydrochloride was dissolved in 250 ml of water containing 6.4 ml of concentrated HCl. To this solution there was added from a dropping funnel, with a drawn out end, in small drops, a solution containing 3.2 g of $NaNO_2$ in 50 ml of water which had been cooled to 5°. Throughout the

entire course of the operation for the preparation of the diazonium salt, the temperature in the flask was maintained at 0 to 5°. The diazotization was controlled by means of starch-iodine paper. (The final test, after the addition of the drops of $NaNO_2$ solution, was made after 15 minutes). The solution of diazonium salt obtained was added in small portions, with energetic stirring, to a solution of 10 g of N-(1-naphthyl)-ethylenediamine dihydrochloride in 500 ml of cold water which contained 16 ml of concentrated HCl. The mixture had a dark violet color. After 15 minutes of standing at room temperature, the solution was heated on a water bath to 60°, and kept at this temperature for 30 minutes. After cooling, a concentrated solution of NaOH was added to it in small portions until the color of the solution changed from dark violet to orange. The addition of alkali was continued until the pH of the solution was 9.6 (approximately). The precipitate which formed was filtered off and dried. The yield of crude product was about 6 g. After two recrystallizations from 50% aqueous methanol, orange colored needle-shaped crystals of N-(1-naphthyl-4-azobenzene)-ethylenediamine were obtained, with m.p. 102-103°.

SUMMARY

1. The synthesis of the reagent for penicillin has been described, with considerable simplification of the syntheses of the intermediate products – β-bromophthalimide and N-(1-naphthyl)-ethylenediamine dihydrochloride. This makes the synthesis accessible to ordinary laboratories.

2. As has been determined in a special investigation, the reagent synthesized by this method is suitable for the purpose of the quantitative determination of penicillin.

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A COLORIMETRIC METHOD

FOR THE QUANTITATIVE DETERMINATION OF PENICILLIN

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A simple, convenient, and specific method for the quantitative determination of penicillin could to a considerable degree facilitate the investigation both of such questions as the use of antibiotics in medicine, and of its industrial preparation. Both previously and at the present time, the most varied modifications of the biological methods for the quantitative determination of penicillin are awkward, and require special conditions for completion (test for bacteria, sterility, etc.) and the simplest of them (the method of serial separation, and the small cup method) are inconvenient.

The objective of the present investigation was the testing and completion of a chemical method for the determination of penicillin, proposed by Scudi [1]. The principle of the method is based on the condensation of penicillin with N-(1-naphthyl-4-azobenzene)-ethylenediamine, followed by the extraction of the colored condensation product from the reaction mixture and the measurement of the intensity of color in a graduated photometer or photoelectric colorimeter.

Goodall and Strafford [2], after using the method of Scudi for analysis, arrived at the conclusion that the method had a high degree of sensitivity. However, they considered it complicated to work with. A considerable simplification of the synthesis of the reagent, N-(1-naphthyl-4-azobenzene)-ethylenediamine, worked out by A.Yaroslavtsev [3], permits the preparation of a reagent for penicillin under the conditions of the ordinary industrial laboratory. This should, in our opinion, also favor the wider introduction of the chemical method for the determination of penicillin into laboratory practice.

Necessary Reagents and Glassware

1) N-(1-naphthyl-4-azobenzene)-ethylenediamine. This is dissolved in benzene in an amount computed to be 100 mg of reagent in 150 ml of benzene. Before use it is washed with an equal volume of 0.05 N NaOH (twice) and with distilled water in a separatory funnel. It is dried by the addition of 10 to 15 g of anhydrous Na_2SO_4.

2) Glycine buffer with pH 2. This is prepared from 60 ml of 0.2 N glycine in 0.2 N NaCl solution (15.01 g of glycine and 11.7 g of NaCl per liter of water) and 54 ml of 0.2 N HCl solution.

3) Chemically pure chloroform. Commercial chloroform is treated with an equal volume of 0.05 N NaOH (three times), then washed with distilled water and dried with $CaCl_2$ or anhydrous Na_2SO_4.

4) Chemically pure benzene. Commercial benzene is frozen at a temperature of 4°, the liquid part being removed by decantation. After this, the benzene is

washed with 1 N HCl solution, 1 N NaOH solution, and finally with distilled water. It is dried with anhydrous Na_2SO_4.

5) A solution of acetic acid in benzene. 5 ml of glacial acetic acid is dissolved in 1 liter of benzene.

6) An extraction mixture of butyl alcohol and benzene. This is prepared from three parts of chemically pure benzene and one part of butyl alcohol (isobutyl is also suitable).

7) Test tubes of 20 ml capacity with ground glass stoppers, graduated to 15 ml in units of 0.1 ml.

8) Cylindrical separatory funnels of 50 ml, with ground glass stoppers and necks drawn out beyond the stopcock, with graduations from 0.1 to 0.5 ml.

The Preparation of a Standard Curve for the Colorimetric Determination of Penicillin

A sample of the Na salt of crystalline Penicillin G was dissolved in distilled water which had been cooled to 0-5°. The penicillin solution in a small measuring flask was placed in an ice bath.

To a series of graduated test tubes containing 2.5 ml portions of glycine buffer and 12.5 ml portions of chloroform, there were added 2 ml portions of a standard solution of penicillin G, containing 10, 20, 30, 40, 50, 60, 80, 100, and 120 γ. The mixture was vigorously shaken for 2 minutes. After the separation of the phases, which took 3 minutes, the aqueous layer was drawn off with a pipette and discarded. The chloroform layer containing the extracted penicillin was dried by the addition to each test tube of 1 or 2 g of anhydrous Na_2SO_4. From each test tube, an exactly 10 ml portion of the dried chloroform solution of penicillin was transferred to separatory funnels which contained 10 mg portions of the reagent in 15 ml of benzene. To this there were then added 3 ml portions of the solution of acetic acid in benzene. The contents of the funnels were shaken and allowed to stand at room temperature for 3 hours (± 3 minutes). At the end of this time, the reaction mixtures in the separatory funnels were shaken with 12 ml each of 0.05 N NaOH solution for 10 seconds. After the separation of the phases, the lower, chloroform-benzene layer was slowly removed. It is here necessary to note that the greatest amount of condensation product was observed on the surface of separation of the two phases. In order to avoid losing it during the removal of the chloroform-benzene mixture, part of the latter (from 0.2 to 0.3 ml) was allowed to remain in all the separatory funnels. In order to completely remove the excess of reagent, which had not gone into reaction, the aqueous-alkaline extracts were shaken twice with 10 ml of chloroform, each time for 10 seconds. Each time, 0.2-0.3 ml of chloroform was permitted to remain in the separatory funnel. To the aqueous-alkaline solutions there were added 0.5 ml portions of concentrated HCl (1.19). The solutions acquired raspberry red colors of different intensities, depending on the amount of condensation product. The colored solutions were quickly treated with 10 ml of the butyl alcohol-benzene mixture. After shaking and separation of the phases, the aqueous layers were discarded, and to the butanol-benzene extracts there were added 2 ml portions of a mixture of absolute alcohol and HCl (5 ml of concentrated HCl in 100 ml of alcohol). After standing for 15 minutes at room temperature, the intensity of the color was measured in a graduated photometer or photoelectric colorimeter. The color which had developed was maintained without change for a period of many hours. The most sensitive color measurements were attained with the use of a 540 mμ filter [1]. In Fig. 1 there is given the standard curve for penicillin G, obtained by color measurements with a graduated Pulfrich photometer in a 30 mm trough with filter S-53.

As can be seen from Fig. 1, the measurements of color intensity in a graduated photometer are proportional to the amount of penicillin in the samples, and are in good agreement with Beer's law.

By color measurements in a highly sensitive photoelectric colorimeter it is possible to determine amounts of penicillin of less than 10 γ ; however, we must note that during this process the percentage of error is increased. This depends in greater degree upon the treatment of the substance under investigation, and upon the care used in carrying out the entire investigation, than upon the photoelectric determination of the intensity of the clolor.

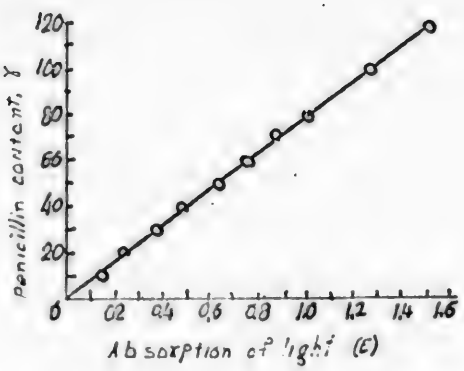

Fig. 1. Standard curve for crystalline penicillin G.

Use of the Method

We tested the colorimetric method for the determination of penicillin in commercial preparations of domestic and foreign manufacture, in all the stages of its industrial preparation, and in urine.

1. Determination of penicillin in urine. For the determination of penicillin in urine, the latter was cooled and quickly filtered through a paper filter, and diluted, in the case of a high penicillin content, with distilled water. The samples taken for analysis had penicillin contents from 10 to 120 γ per 2 ml of urine. The rest of the procedure was carried out in the same way as indicated for the calibration of the standard curve.

Some products of metabolism contained in urine may give condensation products with the reagent, and thus give values higher than the true content of penicillin in urine. In order to avoid such errors, the penicillin was determined in a separate sample after its inactivation. For this purpose, a sample of urine was treated with an equal volume of 0.4 N NaOH and allowed to stand at room temperature for 1 to 2 hours. In this case, the measured amount of "penicillin" was computed from the amount found in the urine before the treatment with alkali.

2. Determination of penicillin in prepared products. For the determination of penicillin in commercial preparations, the entire contents of an ampoule, or of an accurately weighed sample of the total amount, were dissolved in cooled distilled water. The amounts of penicillin were determined in two parallel samples with approximate contents from 10 to 120 γ per 2 ml of solution.

3. Determination of penicillin at various stages of its industrial production.
a) In the determination of penicillin in culture fluid, the latter was filtered through a paper filter and diluted, in case there was a high penicillin content, with cooled distilled water. Samples were taken for analysis with contents of from 10 to 120 γ of penicillin in 2 ml of solution. In order to avoid the influence of byproducts, which might be present in the culture fluid, blank tests were run after inactivation of the penicillin in exactly the same way as indicated for urine.

b) In the determination of penicillin in m/15 phosphate buffer, the latter was diluted with cooled distilled water no less than 50 fold, in order to weaken the buffer properties, and the rest of the determination was carried out as

indicated in the description of the procedure for aqueous solutions of penicillin.

c) For the determination of penicillin in butyl acetate extract, 0.1, 0.2, or 0.4 ml of the latter (depending on the concentration of the penicillin) were diluted with 12.4, 12.3, or 12.1 ml of chloroform, and the mixture stirred. 10 ml portions of the chloroform solutions of penicillin were used for the investigation, as indicated in the procedure.

d) For the concentration and purification of penicillin in its industrial preparation, the buffer extract is treated with a small volume of chloroform. Therefore, for the determination of penicillin, the chloroform extract was diluted 10 to 20 times with pure chloroform, and 0.5 to 1.0 ml samples were added to 12.0 to 11.5 ml of chloroform, followed by mixing. 10 ml of the chloroform solution of penicillin is taken for the investigation, as indicated in the procedure.

e) For the preparation of the Na salt of penicillin and the further concentration of the antibiotic, the latter is transferred from chloroform to bicarbonate solution. For the determination of the penicillin in this stage, samples of the bicarbonate solution were diluted 200 to 400 times with cooled distilled water to bring them down to an approximate content of 10 to 120 γ of penicillin in 2 ml. The rest of the investigation was carried out as indicated in the description of the procedure.

Comparative Data on the Determination of Penicillin by Chemical and Biological Methods

In the table are given the data obtained by the determination of penicillin colorimetrically, iodometrically, and by biological methods.

TABLE

Comparative Data from Chemical and Biological Methods of Determination of Penicillin

Expt. No.	Name of preparation	International units of penicillin found in ampoule		
		Colorimetric method	Iodometric method	Biological method
1	Crystalline penicillin G	1) 100,000 2) 100,000	103,200	1) 90,000 2) 96,000
2	Well purified commercial preparation, non-crystalline	1) 410 2) 420	-	1) 500 2) 600
3	Commercial preparation, non-crystalline, with high content of inert substances	1) 25,000 2) 25,000	23,500	1) 35,000 2) 40,000

As can be seen from the table, in the analysis of crystalline penicillin G, all the methods indicated gave figures close to each other. However, in the analysis of non-crystalline preparations, the figures obtained by the different methods differed considerably from each other. Thus, in the case of the analysis for penicillin of a preparation well purified from accompanying inert substances, but still non-crystalline, the biological method gave a result 20 to 40% greater than the colorimetric method. In addition, parallel samples by the colorimetric method, in the majority of cases, gave results in complete agreement, while the biological method, in parallel samples, gave discrepancies in the penicillin

content of 10 to 15%. In an investigation of non-crystalline penicillins with a high content of inert substances, the figures for penicillin content obtained by the colorimetric and biological methods gave considerable discrepancies, which reached 40 to 60%, while the figures obtained by the iodometric method gave a discrepancy of only 6%. The considerable differences in the figures obtained in the analysis of unpurified preparations of penicillin by the colorimetric and the biological methods may be explained by the fact that the "inert" substances still contain some sort of biologically active materials, which effect the growth of Staphylococcus Aureus, but are not determined by the colorimetric method. However, this hypothesis needs to be verified later. It is not without interest to note that the behavior of the more purified preparations of penicillin and of the less purified in aqueous solutions differ sharply. As can be seen from Fig. 2, a solution of a well purified preparation of penicillin which contains 50γ in 1 ml of distilled water, at a temperature of 18° decomposes much more rapidly than a similar solution of a slightly purified penicillin preparation under the same conditions.

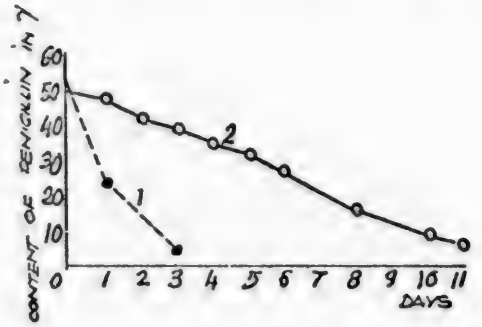

Fig. 2. The stability of penicillin in aqueous solutions in relation to the degree of purity.

1) Well purified; 2) slightly purified

While the first preparation was inactivated to the extent of 50% at the end of the first day and more than 90% at the end of the third day, the second preparation decomposed much more slowly: it was 50% inactivated only at the end of 6 days.

SUMMARY

On the basis of a large number of analyses carried out for the determination of penicillin by the chemical method proposed by Scudi, using our modification, on different dry preparations, urine, and all the stages of its industrial preparation, we can draw the following conclusions:

1) The colorimetric method for the quantitative determination of penicillin with N-(1-naphthyl-4-azobenzene)-ethylenediamine is specific and highly sensitive.

2. The method permits the determination of penicillin in ready-to-use preparations, in urine, and in all the stages of industrial production. In this respect it differs favorably from the biological and iodometric methods.

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THE DEALKYLATION OF β-(2-ALKOXYNAPHTHOYL-1)-PROPIONIC ACIDS AND THE OXIDATION OF β-(2-ETHOXYNAPHTHOYL-1)-PROPIONIC ACID

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Upon heating β-(2-ethoxy (or methoxy) - naphthoyl-1)-propionic acid with hydrobromic acid, there takes place at the same time as the dealkylation of the ether group the cleavage of the ketoacid residue [1]. However, the splitting off of only one alkoxy group should have led to the formation of β-(2-hydroxynaphthoyl-1)-propionic acid, and subsequent alkylation of this acid should have given the higher β-(2-alkoxynaphthoyl-1)-propionic acid. This transition from the readily accessible lower 2-alkoxy-1-naphthoyl propionic acids to their higher homologs was of interest, as in the synthesis of the latter by the Friedel-Crafts method, from the corresponding 2-alkoxynaphthalenes, we encountered difficulties.

Among the methods of cleavage of alkyl ethers of phenols, the most promising, in this case, appeared to us to be the method of dealkylation by means of $AlCl_3$, as the mechanism of this reaction, under the conditions in which it was carried out, excluded the possibility of the hydrolytic action of the hydrogen halide acid on the ketoacid group.

This reaction was tried out by us on two acids – β-(2-ethoxy (and methoxy)-naphthoyl-1)-propionic acids, and in both cases we obtained β-(2-hydroxynaphthoyl-1)-propionic acid, which had not yet been described in the literature*. The structure of this acid was confirmed by us by its transformation into the known 2-hydroxy-1-naphthylbutyric acid.

The possibility of alkylating the hydroxy group in β-(2-hydroxynaphthoyl-1)-propionic acid was tested by us by means of the ethylation of its ethyl ester. Despite the unfavorable distribution of the substituents in the naphthalene ring for this reaction, we obtained without difficulty the ethyl ester of β-(2-ethoxynaphthoyl-1)-propionic acid.

We have previously [1] already cited the fact that oxidation experiments on β-(2-ethoxynaphthoyl-1)-propionic acid did not give clear results. This appeared strange, as upon oxidation of its lower homolog, β-(2-methoxynaphthoyl-1)-propionic acid [3], 2-methoxy-1-naphthoic acid was easily obtained. In renewed experiments on the oxidation of β-(2-ethoxynaphthoyl-1)-propionic acid, we were able to select such conditions for the reaction as to enable us to obtain similar results. We obtained two substances, one of acid, the other of neutral character. The latter was 2-ethoxy-1-naphthaldehyde [4]. The substance with acid properties was the previously unknown 2-ethoxy-1-naphthoyl formic acid. The results of elementary analysis, the formation of a semicarbazone, and the transformation by means of the anil of the acid into the corresponding aldehyde, which is characteristic for aromatic α-ketoacids, in this case into 2-ethoxy-1-naphthaldehyde, demonstrated the structure of this acid.

* The data of Fieser and Peters [2] are erroneous: these authors apparently obtained β-(2 methoxy (or hydroxy) naphthoyl-6)-propionic acids, and not β-(2-methoxy (or hydroxy)-naphthoyl-1)-propionic acids.

The transformations of β-(2-ethoxy (and methoxy)-naphthoyl-1-propionic acids, as carried out in this work, once more confirmed both their structure and the data in the literature concerning β-(2-methoxynaphthoyl-1)-propionic acid.

The latter acquires a special interest in connection with the comparatively recent communication of Bachmann and Horton [5]. These investigators also carried out the condensation of 2-methoxynaphthalene with succinic anhydride in carbon disulfide medium, but obtained different results than were previously reported [3]. The discrepancy in the results, it appears to us, can be explained by the different methods of treatment of the mixtures of substances obtained after condensation.

EXPERIMENTAL

β-(2-Hydroxy-1-naphthoyl)-propionic acid

a) The cleavage of the methoxyl group from 2-methoxynaphthoyl-1-propionic acid. In a round bottomed flask, joined to a reflux condenser, there were placed 1 g of 2-methoxynaphthoyl-1-propionic acid, 35 ml of absolute benzene, and 2 g of aluminum chloride. The reaction was carried out by boiling on a water bath for 5 hours. At the end of the reaction, the greater part of the benzene was distilled off, and ice and hydrochloric acid were added to the residue. The products of reaction were extracted with ether, and the ether solution was washed with a 4% solution of caustic soda.

Upon acidification of the alkaline solution, there precipitated out a substance with m.p. 98-100°. After crystallization from water 0.7 g of 2-hydroxynaphthoyl-1-propionic acid was obtained in the form of a colorless, crystalline substance with m.p. 116-117°. It was very soluble in ether, alcohol, acetone, and hot water, and slightly soluble in cold water.

3.410 mg substance: 8.589 mg CO_2; 1.582 mg H_2O.
3.006 mg substance: 7.584 mg CO_2; 1.359 mg H_2O.
Found %: C 68.69, 68.80; H 5.19, 5.06.
$C_{14}H_{12}O_4$. Computed %: C 68.85; H 4.92.

b) The cleavage of the ethoxyl group from 2-ethoxynaphthoyl-1-propionic acid. 1 g of 2-ethoxynaphthoyl-1-propionic acid, 75 ml of absolute benzene, and 2 g of aluminum chloride were boiled on a water bath for 5 hours. After the distillation of a large part of the benzene, ice and hydrochloric acid were added to the residue. The reaction mixture was then extracted with ether, and the ether solution washed with a 4% solution of caustic soda. Upon acidification of the alkaline solution, a precipitate formed. This was crystallized from water to give 0.6 g of material with m.p. 116.5-117.5°. It was very soluble in hot water and the usual organic solvents.

2.810 mg substance. 7.095 mg CO_2, 1.250 mg H_2O.
Found %: C 68.86; H 4.97.
$C_{14}H_{12}O_4$. Computed %: C 68.85; H 4.92.

The Ethyl Ester of 2-Hydroxynaphthoyl-1-propionic Acid

In a round-bottomed flask joined to a reflux condenser there were placed 2.5 g of unpurified 2-hydroxynaphthoyl-1-propionic acid, 40 ml of absolute alcohol, and 1.2 ml of sulfuric acid (1.84). The reaction was carried out by boiling on a water bath for 6 hours. At the end of the reaction, the alcohol was driven off in vacuum, and the residue, after the addition of water, was extracted with ether. The ether solution was washed with water, and a 10% solution of sodium bicarbonate, and dried with sodium sulfate. After the ether had been driven off, the residue was crystallized from alcohol. There was obtained 1.8 g of the ethyl ester of 2-hydroxynaphthoyl-1-propionic acid, in the form of slightly colored

crystals with m.p. 92-93°, very soluble in ether, alcohol, and acetone, and crystallizing well from aqueous alcohol.

3.708 mg substance: 9.588 mg CO_2; 1.994 mg H_2O.
2.781 mg substance: 7.193 mg CO_2; 1.475 mg H_2O.
Found %: C 70.52, 70.54; H 6.01, 5.94.
$C_{16}H_{16}O_4$. Computed %: C 70.59; H 5.88.

Upon saponification of 0.8 g of the ethyl ester with m.p. 92-93° with an alcoholic solution of caustic potash, 0.5 g of 2-hydroxynaphthoyl-1-propionic acid was obtained with m.p. 116.5-117.5°.

The Reduction, by the Clemmensen Method, of 2-Hydroxynaphthoyl-1-propionic Acid

0.3 g of 2-hydroxynaphthoyl-1-propionic acid, 1.5 mg of glacial acetic acid, 1.5 mg of toluene, 1.5 ml of hydrochloric acid (1:1) and 1.6 g of amalgamated zinc were boiled for a period of 20 hours, 0.5 ml portions of hydrochloric acid (1:1) being added 3 times during the course of the reaction. At the end of the heating, the cooled reaction mass was extracted with ether, and the ether solution was washed with a 4% solution of caustic soda. Upon acidification of the alkaline solution, an oily substance precipitated. This, after crystallization from a mixture of benzene and chloroform, had m.p. 134-136°, and was identical with the 2-hydroxynaphthyl-1-butyric acid obtained by the cleavage of alkoxyl groups in 2-methoxy- and 2-ethoxynaphthoyl-1-butyric acids [1].

The Alkylation of the Ethyl Ester of 2-Hydroxynaphthoyl-1-Propionic Acid

0.75 g of the ethyl ester of 2-hydroxynaphthoyl-1-propionic acid, 10 ml of a 5% alcoholic solution of caustic potash, and 5 g of ethyl iodide were heated on a water both for a period of 4 hours. At the end of the heating, the solution was filtered from the potassium iodide, and the filtrate was evaporated to dryness in vacuum. Water was added to the residue, and the solution was extracted with ether. The ether solution was washed with a solution of soda, then with water, and dried with sodium sulfate. The ether was driven off, and the residual oil was dissolved in alcohol. Upon cooling, a substance separated in the form of colorless crystals with m.p. 50-51°. This substance was identical with the ethyl ester of 2-ethoxynaphthoyl-1-propionic acid, obtained by the esterification of 2-ethoxy-1-naphthoyl-propionic acid.

The Oxidation of β-(2-Ethoxynaphthoyl-1)-propionic Acid

a) 2-Ethoxynaphthoyl-1-formic acid. To a solution of sodium hypochlorite, obtained by passing chlorine into 210 ml of a 9% solution of caustic soda until there was a gain in weight of 11.42 g, 950 ml of water was added, and then there was added in small portions 7 g of 2-ethoxynaphthoyl-1-propionic acid. The reaction mixture obtained was heated on a water bath for 25 minutes, and then boiled for one hour on a gauze. At the end of the heating, the reaction mixture was quickly cooled and filtered from the small amount of precipitate formed. (For the treatment of the latter, see part b). The filtrate, after the addition of sodium bisulfite, was carefully acidified with 10% hydrochloric acid. The precipitated material was filtered with suction and dried. 2.7 g of unpurified material was obtained, from which fractional crystallization* from very small amamounts of alcohol gave 1.25 g of 2-ethoxynaphthoyl-1-formic acid with m.p. 159-161°.

3.728 mg substance: 9.416 mg CO_2; 1.708 mg H_2O.
Found %: C 68.88; H 5.11.
$C_{14}H_{12}O_4$. Computed %: C 68.85; H 4.91.

*It was more convenient to purify 2-ethoxynaphthoyl-1-formic acid by its transformation by way of the ethyl ester.

b) 2-Ethoxy-1-naphthaldehyde. The material which did not dissolve in alkali (cf part a) was transferred to a separatory funnel, water was added, and it was extracted with ether. The ether solution was dried with sodium sulfate. After the ether had been driven off, the residue was crystallized from alcohol. 0.5 g of 2-ethoxy-1-naphthaldehyde was obtained in the form of yellow crystals with m.p. 109-110.5°. It was very soluble in ether, acetone, and hot water.

4.055 mg substance: 11.563 mg CO_2; 2.220 mg H_2O.
Found %: C 77.77, H 6.13.
$C_{13}H_{12}O_2$. Computed %: C 78.00; H 6.00.

The Anil of 2-Ethoxy-1-naphthaldehyde

0.1 g of 2-ethoxy-1-naphthaldehyde (m.p. 109-110.5°) and 0.05 g of aniline were boiled in alcoholic solution for a period of 5 hours. The alcohol was driven off in vacuum and the residue crystallized from alcohol. The substance obtained had m.p. 71-73° [3].

3.352 mg substance: 10.212 mg CO_2; 1.810 mg H_2O.
Found %: C 83.08; H 6.04.
$C_{19}H_{17}ON$. Computed %: C 82.90; H 6.18.

The Ethyl Ester of 2-Ethoxynaphthoyl-formic Acid

a) In a round-bottomed flask, joined to a reflux condenser, there were placed 0.5 g of 2-ethoxynaphthoyl-1-formic acid (m.p. 159-161°), 7.5 ml of absolute ethyl alcohol, and 0.2 ml of sulfuric acid (1.84). The reaction was carried out by boiling on the water bath for a period of 6 hours. After the usual treatment, 0.4 g of the ethyl ester of 2-ethoxynaphthoyl-1-formic acid was obtained in the form of slightly yellowish crystals with m.p. 70.5-71°. They were very soluble in ether and acetone, and could be crystallized from alcohol.

3.620 mg substance: 9.365 mg CO_2; 1.500 mg H_2O.
Found %: C 70.55; H 5.87.
$C_{16}H_{16}O_4$. Computed %: C 70.59; H 5.89.

b) 9.2 g of unpurified 2-ethoxynaphthoyl-1-formic acid (melting range 116-128°), 110 ml of absolute ethyl alcohol, and 4.5 ml of sulfuric acid were boiled for a period of 6 hours in a round-bottomed flask with a reflux condenser. After the usual treatment, 1.5 g of unreacted acid and 3.5 g of the ethyl ester of 2-ethoxynaphthoyl-1-formic acid, with m.p. 69-70°, were obtained.

3.986 mg substance: 10.359 mg CO_2; 2.200 mg H_2O.
Found %: C 70.88; H 6.18.
$C_{16}H_{16}O_4$. Computed %: C 70.59; H 5.89.

Upon saponification of 0.2 g of the ethyl ester of 2-ethoxynaphthoyl-1-formic acid (m.p. 69-70°) by means of a 6% alcoholic solution of caustic potash (in the cold) the free 2-ethoxynaphthoyl-1-formic acid was obtained with m.p. 160-161°.

3.255 mg substance: 8.222 mg CO_2; 1.434 mg H_2O.
Found %: C 68.88; H 4.93.
$C_{14}H_{12}O_4$. Computed %: C 68.85; H 4.51.

The Semicarbazone of 2-Ethoxynaphthoyl-1-formic Acid

0.07 g of semicarbazide hydrochloride and 0.06 g of potassium acetate were ground with a small amount of absolute methyl alcohol, and after the evolution of heat and the liquefaction of the mass, an additional small amount of methanol was added. The precipitate was filtered with suction, and the filtrate was added to a solution of 0.1 g of 2-ethoxynaphthoyl-1-formic acid in a small amount of absolute methyl alcohol. The reaction mixture was then allowed to stand at room temperature. After two days, there precipitated from solution a crystalline material

which, after crystallization from absolute methyl alcohol, had m.p. 188.5-189.5°.

5.140 mg substance: 11.291 mg CO_2; 2.240 mg H_2O.
Found %: C 59.91; H 4.88.
$C_{15}H_{15}O_4N_2$. Computed %: C 59.80; H 4.98.

The Transformation of 2-Ethoxynaphthoyl-1-formic Acid Into 2-Ethoxy-1-naphthaldehyde

A mixture of 0.5 g of 2-ethoxynaphthoyl-1-formic acid, 0.2 g of aniline, and 3 ml of absolute alcohol was boiled for a period of 1 hour in a round-bottomed flask with a reflux condenser. At the end of the heating, the alcohol was driven off in vacuum, and the residue was dissolved in chloroform. The chloroform solution obtained was washed several times with 3% hydrochloric acid, then with water, and dried with sodium sulfate. After the chloroform had been driven off, the residue was ground with alcohol and then crystallized from alcohol to give yellow crystals with m.p. 108-110°.

In a melting point test, a mixed sample of this substance with 2-ethoxy-1-naphthaldehyde obtained directly from the oxidation of 2-ethoxynaphthoyl-1-propionic acid gave no depression.

4.000 mg substance: 11.440 mg CO_2; 2.15 mg H_2O.
Found %: C 77.99; H 6.02.
$C_{13}H_{12}O_2$. Computed %: C 78.00; H 6.00.

SUMMARY

1. The cleavage of the alkoxy group in β-(2-methoxy (and ethoxy)-naphthoyl-1)-propionic acids has been effected by heating these compounds with $AlCl_3$ in benzene solution, to give β-(2-hydroxynaphthoyl-1)-propionic acid.

2. The oxidation of β-(2-ethoxynaphthoyl-1)-propionic acid has given 2-ethoxy-1-naphthoyl-formic acid and 2-ethoxy-1-naphthaldehyde.

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*See CB translation p. 2411 ff.

ON THE REACTIONS OF ALIPHATIC DIAZO COMPOUNDS WITH UNSATURATED COMPOUNDS

VI. THE ETHYL ESTER OF 1-ACETOXYCYCLOPROPANE-2 CARBOXYLIC ACID

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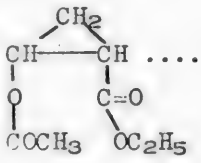
The ethyl ester of 1-acetoxycyclopropane-2 carboxylic acid (I) has been obtained by us * as the chief constituent of the condensation product of vinyl acetate with diazoacetic ester in the presence of Natur Cupfer C or $CuSO_4$ as catalyst.

$$CH_3OCO{-}CH{=}CH_2 + N_2CH{-}COOC_2H_5 \xrightarrow[CuSO_4]{Cu} N_2 + \text{(I)} \quad \ldots\ldots\ldots \quad (1)$$



(I)

$$2N_2CHCOOC_2H_5 \xrightarrow[CuSO_4]{Cu} 2N_2 + C_2H_5OOC{-}CH{=}CH{-}COOC_2H_5 \quad \ldots\ldots\ldots\ldots \quad (2)$$

(II)

Here (1) is the chief direction of the reaction and (2) is a suggested side reaction (see further). The reaction was carried out under conditions described previously [1] for vinylbutyl ether. In contrast to the experiments with vinylbutyl ether, the condensation with vinyl acetate was accompanied by considerable tarring, especially in the case where "crude" diazoacetic ester was used [cf. Experimental section (I,a and Table 2)]. In the work with purified diazoacetic ester (see I,a), the yields of condensation product reached an average of 63-66% of theory (Table 1), while in the work with the crude ester the yields fluctuated within the limits from 39 to 56% of theory (Table 2).

The condensation product, which corresponded to the empirical formula of the ester (I), $C_8H_{12}O_4$, in composition, was not a single compound, as in the case of the experiments with vinylbutyl ether [1]. Under the action of a cold solution of potassium permanganate, it partially used up the oxidizing agent. This removed the unsaturated impurity, which was isomeric in composition with the cyclic ester (I). The latter could be isolated in pure form from the oxidation products in a yield of 80 to 82% of the initial weight of the condensation product. Among the oxidation products were found oxalic and acetic acids. The presence of these acids made it possible to judge the nature of the unsaturated impurities of isomeric composition which accompanied the ester. The most probable hypothesis was the formation of the ethyl ester of fumaric acid (II) according

* Experimental Part completed with the participation of Student Z. N. Kudryavtseva.

to Equation (2). This, as is known [2], is a byproduct also in other syntheses with diazoacetic ester.

The content of fumaric ester in percentage of the weight of condensation product can be approximately computed by a comparison of the permanganate used up in the oxidation of the crude product with the amount of oxidizing agent required by Equation (3):

$$C_2H_5OOC-CH=CH-COOC_2H_5 + 4O_2 \longrightarrow 2HOOC-COOH + 2CH_3COOH \ldots\ldots \quad (3)$$
(II)

This computation showed that the content of fumaric ester (II) in the condensation product could be estimated as about 3% of the weight of the latter; 97%, therefore, consisted of the cyclic ester (I) (actually, as has been indicated, it was possible to isolate 80 to 82% of the ester after oxidation). The "unsaturatedness" of the condensation product obtained in syntheses with crude diazoacetic ester is greater, and in several experiments reaches 11% of the weight of the initial product • (Table 3).

The pure cyclic ester, like the original condensation product, had the composition $C_8H_{12}O_4$, corresponding to formula (I).

Not only in the cold, but even upon heating to 80°, the ester barely used up 3% of the solution of potassium permanganate. Upon boiling with the solution of permanganate, slow oxidation to succinic and acetic acids took place. This was also accepted by us, in relation to previous observations [1,3] as an indication of cyclic structure:••

$$C_2H_5OOC-\underset{\diagdown\,\diagup}{\overset{CH_2}{CH}}-CH-OCOCH_3 + 1.5O_2 + H_2O \rightarrow HOOC-CH_2-CH_2-COOH + 2CH_3COOH \ldots\ldots \quad (4)$$

The ester (I) may be regarded as a derivative of the non-existing 1-hydroxycyclopropane-2-carboxylic acid (III):

$$HO-\underset{\diagdown\,\diagup}{\overset{CH_2}{CH}}-CH-COOH \qquad + \qquad HO-\underset{\diagdown\,\diagup}{\overset{CH_2}{CH}}-CH_2$$
(III) (IV)

whose lack of stability was shown by us to be related to the inability of cyclopropanol (IV) [1] to exist.

Later [4,5] it was shown by us that the ester (V) and especially the acid (VI):

$$C_4H_9O-\underset{\diagdown\,\diagup}{\overset{CH_2}{CH}}-CH-COOC_2H_5; \qquad C_4H_9O-\underset{\diagdown\,\diagup}{\overset{CH_2}{CH}}-CH-COOH,$$
(V) (VI)

are very easily hydrolyzed in the presence of dilute acids [for example, (VI) is hydrolyzed even upon boiling with 20% acetic acid] with the cleavage of the

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• The production of acetic and oxalic acids still does not incontrovertibly show the presence of fumaric ester in the mixture. These acids can also be formed by the oxidative cleavage of the isomeric esters (I,a) and (I,b), products of the isomerization of the cyclic ester (I):
$C_2H_5OOC-CH = CH-CH_2OCOCH_3$ (I,a) and $C_2H_5OOC-CH_2-CH = CH-OCOCH_3$ (I,b).

•• In the presence of an open chain with a double bond (cf. for example, the isomeric esters I,a and I,b) oxidation would give acids with a number of carbon atoms less than four. On the relation between structure and the formation of succinic acid during oxidation, cf. on butoxy-cyclopropane carboxylic acid and its ester [1,4].

butoxyl group. However, in none of the experiments were we able to isolate 1-hydroxycyclopropane-2-carboxylic acid (III). Instead of (III), we obtained either a product of its isomeric transformation, aldehydosuccinic acid (VII), or a "crotonization" product of the latter, the unsaturated aldehydo acid of the composition $C_8H_{10}O_5$ (VIII) [5]:

$$HOOC-CH_2-CH_2-CH=O; \qquad (VII)$$

$$HOOC-CH_2-CH_2-CH=\underset{\displaystyle CH=O}{\overset{\displaystyle |}{C}}-CH_2-COOH. \qquad (VIII)$$

We assumed that this lack of success must be ascribed to the isomerizing influence of the hydrogen ions in whose presence the trimethylene ring in the acid (III) is broken. Upon heating with water in the presence of alkaline agents or neutral salts, the ester (V) and the acid (VI) did not split off the butoxyl group, and therefore it was not possible to carry out the hydrolysis to the hydroxyacid (III) under these conditions. However, it appeared that it was precisely under these conditions that the hydroxyacid (III) should have had the greatest stability, as it is known that the cyclopropane ring is especially easily broken under the influence of acids, and not of alkalies, and still less of neutral salts. Therefore it was possible to assume that the newly obtained ester (I) with the ester group "$-O-COCH_3$' in the ring would be the most suitable object for transition to the cyclic hydroxyacid (III).

Experiments showed that the ester (I) readily undergoes complete hydrolysis upon boiling with 5% caustic soda or upon boiling with water in the presence of calcium hydroxide, and undergoes hydrolysis with much greater difficulty, but still completely, upon boiling with water in the presence of barium carbonate or chalk. However, even under these conditions, the hydroxyacid (III) was not observed even in the form of salts in the cooled aqueous solutions when the hydrolysis was carried out. These solutions, even before acidification, gave a reaction for the aldehyde group, and under the action of the suitable reagent gave a precipitate of the semicarbazone of the acid $C_8H_{10}O_5$ (VIII).

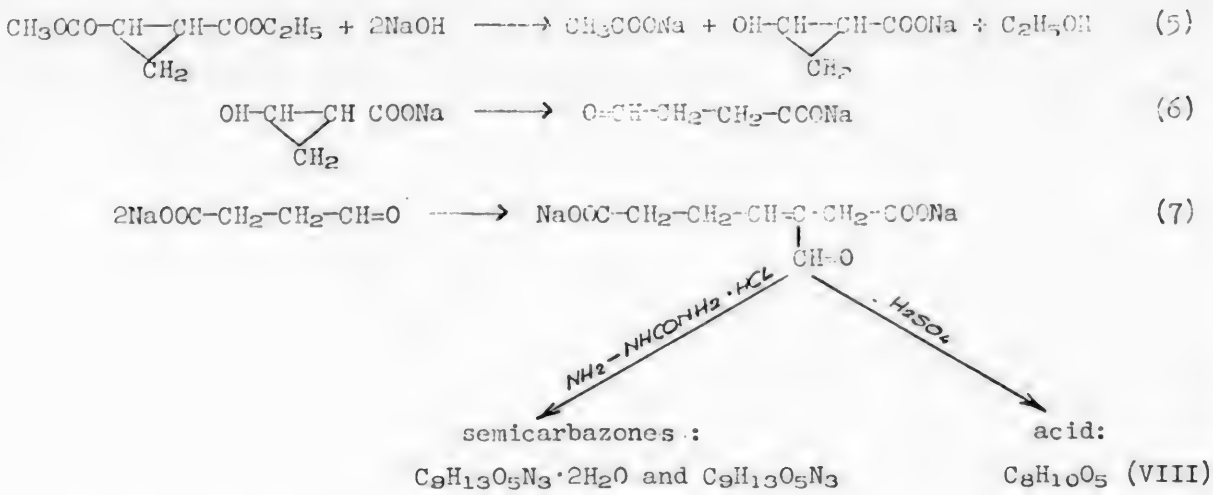
The semicarbazone of this acid, as we have shown, can be obtained in two forms: with m.p. 187-188°, corresponding to the composition $C_9H_{13}O_5N_3 \cdot 2H_2O$, and with m.p. 197-198°, with the composition $C_9H_{13}O_5N_3$. From the acidified aqueous solutions, ether extraction also gave the free acid (VIII), in addition to acetic acid. The results obtained may be interpreted in the following manner.

The Na, Ba, or Ca salt of the hydroxyacid (III), formed in the hydrolysis of (I), is immediately isomerized in the heated aqueous solution into the corresponding salt of aldehydosuccinic acid (VII), which under these conditions, in conformity with previous results [6], undergoes further change, and is converted into a salt of the complicated aldehydoacid (VIII). The latter was also detected by us in aqueous solutions as a final product of hydrolysis.

Similar mechanisms, apparently, must also be ascribed to the transformations of the Ba and Ca salts in aqueous solutions. However, in a preceding communication, it was shown [6] that the Ca salt of aldehydosuccinic acid is not changed upon heating its aqueous solution for 3 or 4 hours on the water bath.

Consequently, in this case too, upon saponification of the ester (I) in the presence of chalk, we must expect the formation in the solution of the unaltered Ca salt of aldehydosuccinic acid.

The transformation of the Ca salt of this acid into the Ca salt of acid (VIII), which was actually observed in this experiment, could be ascribed only to the fact that the saponification of the ester (I) in the presence of water and chalk took place under conditions of lengthy boiling of this mixture (several days).



We must then assume that the more stringent conditions favor the transformation which we had not previously observed [6].

The corresponding experiments, arranged with aqueous solutions of aldehydosuccinic acid obtained from the hydrolysis of the ester (I) in the presence of sulfuric acid, confirmed this assumption. When the hydrolysis was carried out with 10% sulfuric acid in acid aqueous solutions, the fact that aldehydosuccinic acid was actually formed was shown by means of a p-nitrophenylhydrazine test, as well as by the formation of the semicarbazone of this acid from a solution neutralized with chalk, under mild conditions (cf. IV, e).

From all that has been said above, it is necessary to draw the conclusion that 1-hydroxycyclopropane-2-carboxylic acid is extremely unstable, and isomerizes even in aqueous solutions upon heating with dilute mineral acid. Just as unstable are the aqueous solutions of its salts, when heated to 100°, both in the absence as well as in the presence of hydroxyl ions (cf. IV, a-e).

It is very possible that even in the free condition, this acid, when prepared by any method whatever, would be incapable of existence, exactly like the simplest alcohol of the trimethylene series, cyclopropanol [7]. The ethers of cyclopropanol (IX) have been described, but it has not yet been possible to obtain the ester of this alcohol, acetoxycyclopropanol (X). At the moment of formation, there takes place the isomerization into the acetate of allyl alcohol [8]:

(IX) (X)

The cyclic ester (I), which we have described, is apparently the first representative of this series of trimethylene compounds in which the structure of acetoxycyclopropane (X) actually exists. It is very possible that success in the synthesis of this compound (I) must be ascribed to the favorable stabilizing influence of the carbethoxyl in position 2 of the three-membered ring.

However, a not unimportant role can here be played by the conditions of synthesis of the ester (I) as well, as attempts to obtain the ester (X) by other authors have been based on reactions which have nothing in common with the reaction described above.

EXPERIMENTAL

I. The Condensation of Diazoacetic Ester with Vinyl Acetate

a) Starting Compounds

Diazoacetic ester. Used in our syntheses both "crude"* and purified by distillation with steam in vacuum.*

Vinyl acetate. B.p. 72-73°. Used in syntheses both freshly distilled, after drying of the commercial preparation with sodium sulfate, and regenerated after use in experiments. Storage under pyrogallol or hydroquinone.

Catalyst: Natur Cupfer C, copper sulfate (anhydrous).

b) Procedure

400 ml of freshly distilled vinyl acetate and 1 g of Natur Cupfer C were placed in a round-bottomed three-necked flask fitted with a ground-in dropping funnel, a mercury seal with a stirrer and a ball condenser** whose free end was joined to a gasometer filled with water. The flask was heated with the stirring going until the mixture boiled gently on the water bath, and then, without interrupting the boiling and the stirring, there was slowly added from the dropping funnel a mixture of 80 g of pure diazoacetic ester (cf. I, a) and 80 ml of freshly distilled vinylacetate. The nitrogen evolved by the reaction of the reagents was collected in the gasometer. The amount of nitrogen collected almost corresponded to that computed for this reaction from the equation.

Usually, the evolution of nitrogen ceased completely from 20 to 30 minutes after the end of the addition of the mixture. The reaction could then be considered complete. After this, the cooled solution was filtered from the copper (without suction) and the excess vinyl acetate was distilled off on a water bath (sometimes with the use of a slight vacuum). The yield of regenerated vinyl acetate was 295 g, which amounted to 90% of theory (computed on the basis of the amount which had reacted).

The crude reaction product that remained after distillation of the solvent was distilled in vacuum. The boiling point was 91-95° at 7 mm (83% of the weight of the distillate went over between 94 and 95° at 7 mm). Yield 86 g (71.6% of theory, based on the formula $C_8H_{12}O_4$; see below). The undistilled residue was in the form of a thick tarry mass. Weight 9 g.

The procedure given above is a description of the experiment in which we obtained the best yield of reaction product and the least tarring. In other experiments, listed in Table 1, the yields of reaction product were somewhat lower (63-66%), and tar formation was somewhat greater. This could be ascribed to the changed conditions for carrying out the experiment, and to the weight ratios of the reagents, as well as to the choice of catalyst ($CuSO_4$). Copper sulfate acts more vigorously than Natur Cupfer C. Under these conditions, ordinary copper generally does not react. It is desirable to use a great excess of vinyl acetate compared to the diazoacetic ester used for the reaction. The length of the experiment has little influence on the yield of reaction product.

In Table 2 are listed the results of experiments in carrying out the condensation with crude diazoacetic ester. The yields of the reaction product are here appreciably lower than those noted in Table 1, and fluctuate within fairly wide limits, but the cause is still unclear. In this series of experiments, after the reaction product had been distilled off there remained a large amount of tarry products.

* For notes by the author on the synthesis of this compound, as well as the necessary literature, see Communication II of this series [1].

** For the polished surfaces there could be substituted rubber stoppers, protected from within by cork packing

Syntheses Carried Out with Purified Diazoacetic Ester

Expt. No.	Diazoacetic ester, g	Vinyl acetate, ml	Catalyst g	Duration of expt., hrs.	Yield of reaction product, % theory	Boiling point of reaction product
1	20	220	0.5 Cu	5	63.1	103-106° at 16 mm
2	40	420	0.7 Cu	7.5	63.0	101-104 at 14 mm
3	80	480	1.0 Cu	8.5	71.6	91-95 at 7 mm
4	23	170	0.4 $CuSO_4$	2.5	66.8	88.5-91 at 6.5 mm
5	34.4	200	0.3 $CuSO_4$	2.5	65.9	87-90 at 6 mm

TABLE 2

Syntheses Carried Out with Crude Diazoacetic Ester

Expt. No.	Diazoacetic ester, g	Vinyl acetate, ml	Cu, g	Duration of experiment, hours	Yield of reaction product, % theory	Boiling point of reaction product
1	80	480	1.0	8.5	36.5	98-101° at 12 mm
2	60	360	0.5	4.0	39.0	72-80 at 3-5 mm
3	50	450	0.7	8.0	50.8	74-77 at 4 mm
4	67	640	1.0	8.0	56.0	72-78 at 3-4 mm

II. Investigation of the Product of Condensation

a) Analytic data

B.p. 94-95° at 8 mm; d_4^0 1.121, d_4^{20} 1.074; n_α^{20} 1.433, MR_α 40.96. $C_8H_{12}O_4$. Computed: MR_α 40.06.

0.1324 g substance: 0.2707 g CO_2; 0.0820 g H_2O.
0.1214 g substance: 0.2491 g CO_2; 0.0744 g H_2O.
Found %: C 55.76, 55.97; H 6.91, 6.84.
$C_8H_{12}O_4$. Computed %: C 55.81; H 6.98.

0.2426 g substance; 16.46 g C_6H_6. Δt 0.45°.
0.2570 g substance: 15.61 g C_6H_6. Δt 0.49°.
Found: M 163.8, 168.0.
$C_8H_{12}O_4$. Computed: M 172.1.

b) 1-Acetoxycyclopropane-2-carboxylic ester

For the preparation of the cyclic ester from the condensation product the latter was shaken in the cold with a 2% solution of potassium permanganate until the color of the permanganate ion no longer disappeared from the solution in the cold.

After the excess of oxidizing agent had been removed with bisulfite, and after filtration, the cyclic ester separated from the aqueous layer, and both this layer and the manganese dioxide were extracted with ethyl ether. The ether extracts were united with the main product and dried with sodium sulfate, and the solvent was driven off. The ester was then distilled in vacuum. B.p. 90-92° at 7 mm.

In Table 3 are listed the results of several experiments on the production

TABLE 3

Experiments on the Oxidation of the Condensation Product in the Cold with a Solution of Permanganate

Expt. No.	Original condensation product: Method of preparation of original product	Amount, g	Permanganate used up for oxidation, g	Fumaric ester in condensation product, (wt. %)	Yield of 1-acetoxycyclopropanol-2-carboxylic ester, %	Boiling point of 1-acetoxycyclopropanecarboxylic ester
1	Pure diazoacetic ester plus $CuSO_4$.....	56.7	8	3.0	82	99-92.5° (at 7 mm)
2	Same plus Natur Cupfer C	86.0	12	3.1	79	89-93° (at 7 mm)
3	Crude diazoacetic ester plus Natur Cupfer C	90	37	11.9	66	69-72° (at 2 mm)

of 1-acetoxycyclopropane-2-carboxylic ester from the condensation product.

In the 2nd and 3rd columns of Table 3 are indicated the respective methods of preparation of the condensation product used as the starting material in the oxidation reaction, and the amount (in grams) used in this reaction. From the data of the table it follows that the condensation product obtained from pure diazoacetic ester contained a smaller amount of the unsaturated fumaric ester (column 5) than the product which had been obtained from the work with the crude diazoacetic ester. The computation of the amount of unsaturated impurity in the cyclic ester was made on the basis of the data given in column 4 on the permanganate used up in the oxidation of the unsaturated ester according to Equation (3).

The computation is, of course, approximate.

From the data given in column 5 it follows that the yields of pure cyclic ester also depended to a considerable degree on the degree of purity of the diazoacetic ester used for the synthesis of the original condensation product.

Below are given several physical constants, as well as the necessary analytical data, for the pure ethyl ester of 1-acetoxycyclopropane-2-carboxylic acid.

B.p. 90-92.5° at 7 mm; d_4^{20} 1.074; n_α^{20} 1.433; MR_α 40.96.
$C_8H_{12}O_4$. Computed: MR_α 40.06.

0.0730 g substance: 0.1485 g CO_2; 0.0484 g H_2O.
0.0984 g substance: 0.1994 g CO_2; 0.0610 g H_2O.
Found %: C 55.47, 55.26; H 7.31, 6.92.
$C_8H_{12}O_4$. Computed %: C 55.81; H 6.98.

c) Investigation of the Oxidation Products of the Condensation Product

After the removal of the cyclic ester, the aqueous solution of the oxidation products was concentrated on a water bath, acidified with sulfuric acid, and subjected to distillation with steam to remove the supposed volatile organic acids from those which were non-volatile with steam and remained in the distillation flask.

After the aqueous distillate had been neutralized with 0.1 N NaOH and concentrated, it was used for the preparation of silver salts of the organic acids being sought. The analytical data for the salts corresponded to the composition of silver acetate:

0.0949 g substance: 0.0612 g Ag.
0.1408 g substance: 0.0909 g Ag.
Found %: Ag 64.43, 64.63.
$C_2H_3O_2Ag$. Computed %: Ag 64.68.

The acid aqueous solution of non-volatile acids was extracted with ether in an extractor. The oxalic acid obtained in this manner was converted for the purpose of proof, into the calcium salt, whose analysis gave the following results:

0.1639 g substance: 0.0629 g CaO.
0.1520 g substance: 0.0582 g CaO.
Found %: Ca 27.43, 27.36.
$CaC_2O_4 \cdot H_2O$. Computed %: Ca 27.30.

Thus, acetic and oxalic acids were found.

III. The Oxidation of 1-Acetoxycyclopropane-2-carboxylic Ester

In a flask fitted with a stirrer, a reflux condenser, and a dropping funnel there were placed 5.1 g of the cyclic ester and 60 ml of a 3% solution of potassium permanganate. With the stirrer in operation, the mixture was heated on the water bath at 80° (bath temperature) for a period of one hour. At the end of this time, no disappearance of the violet color was noted. Only when the flask was heated over the open flame to the boiling point of the mixture was the disappearance of the permanganate color observed. When this had been obtained, new portions of oxidizing agent were added from the dropping funnel and the mixture was heated with vigorous stirring until 33 ml of 3% permanganate solution was used up. This corresponded to the amount of oxidizing agent computed from equation (4). After completion of the oxidation, filtration from the manganese dioxide, and washing of the latter with hot water, the filtrate and the wash water were subjected to distillation. The distillate gave only a slight cloudiness upon the addition of a solution of p-nitrophenylhydrazine acetate. The residual salt solution was concentrated to a volume of 30 to 40 ml, acidified with 12 ml of 50% sulfuric acid, and after filtration from the potassium sulfate, was extracted with ether in an extractor. This gave 0.7 g of succinic acid with m.p. 179-181° (m.p. 182-183° after crystallization from water) and about 0.6 g of acetic acid with b.p. 52-54° at 100 mm. A mixed sample with known succinic acid gave no depression of the melting point. A determination of the acid equivalent, and an analysis of the silver salt of the acid gave the results required by theory.

Determination of the acid equivalent:

0.111[illegible] g substance. used up 18.8 ml 0.1 N NaOH.
Found: equiv. 59.20.
$C_2H_4(COOH)_2$. Computed: equiv. 59.03.

Analysis of silver salt:

0.2108 g substance: 0.1364 g Ag.
Found %: Ag 64.71.
$C_4H_4O_4Ag_2$. Computed %: Ag 65.00.

The acetic acid was characterized by means of its silver salt:

0.1316 g substance: 0.0852 g Ag.
0.1915 g substance: 0.1229 g Ag.
Found %: Ag 64.74, 64.21.
$C_2H_3O_2Ag$. Computed %: Ag 64.67.

IV. The Hydrolysis of 1-Acetoxycyclopropane-2-carboxylic Ester

a) In the presence of caustic soda

51.6 g of the ester was hydrolyzed by boiling and energetic stirring with 60 ml of 5% caustic soda. At the end of the hydrolysis (disappearance of the oily layer of ester) the solution was neutralized with H_2SO_4 and concentrated to a volume of 50 ml; 10 ml of the solution was mixed with a concentrated solution of 2 g of semicarbazide hydrochloride.

After crystallization from water, the semicarbazone had m.p. 187-188°.

0.1242 g substance. 0.1767 g CO_2; 0.0644 g H_2O.
0.0780 g substance: 10.5 ml N_2 (20°, 745.5 mm).
0.0552 g substance: 7.3 ml N_2 (20°, 760 mm).
Found %: C 38.80; H 6.35; N 15.14, 15.20.
$C_9H_{13}O_5N_3 \cdot 2H_2O$. Computed %: C 38.70; H 6.14; N 15.07.

The remaining 40 ml of solution was acidified with sulfuric acid and filtered from the Na_2SO_4, then extracted with ether in an extractor. The ether extract consisted, at the end of the extraction, of two layers: the lower layer was a heavy oil, and the upper was the ether layer. Upon careful evaporation of the ether layer and cooling of the oil, this crystallized to give a solid acid, which after filtering and washing with ether melted at 99°. A mixed melting point test with the acid $C_8H_{10}O_5$ [4,5] gave no depression. Yield 4.3 g (16% of theory).

In order to confirm the identity of the acid under investigation, the semicarbazone was prepared. This had m.p. 187-188°, and did not give a depression with the semicarbazone obtained in this experiment from the solution.

0.0915 g substance. 12.5 ml N_2 (19°, 740 mm).
Found %: N 15.34.
$C_9H_{13}O_5N_3 \cdot 2H_2O$. Computed %. N 15.07.

It was later found that the semicarbazone with the composition $C_9H_{13}O_5N_3 \cdot 2H_2O$ after two recrystallizations from water (with the use of bone charcoal to remove the yellow color) and long drying in vacuum above sulfuric acid, lost water of crystallization and melted at 198-199°*:

0.1133 g substance: 7.3 ml N_2 (23°, 737 mm).
Found %: N 17.12.
$C_9H_{13}O_5N_3$. Computed %: N 17.28.

On evaporation of the ether mother liquid which remained after the removal of the acid $C_8H_{10}O_5$, there was obtained acetic acid, which had been formed by the hydrolysis of the ester. For this, the residue from the evaporation was distilled in vacuum. B.p. 53-54° at 100 mm. Yield 4 g (22% of theory). The analysis of the silver salt obtained from this fraction gave the following results:

0.1395 g substance: 0.0901 g Ag.
Found %: Ag 64.59.
$C_2H_3O_2Ag$. Computed %: Ag 64.68.

b) In the presence of $Ca(OH)_2$

Experiment 1. 15 g of the cyclic ester was subjected to hydrolysis under the same conditions as in (IV,a), but in the presence of 15 g of calcium hydroxide. At the end of the hydrolysis, the solution was filtered, and the calcium salts of organic acids present in solution were decomposed with the computed amount of oxalic acid. Subsequent filtration and evaporation of the filtrate in vacuum led to the formation of a dry residue, from which an extraction with ether

*In previous communications [5,6], the melting point 198-199° and the composition $C_9H_{13}O_5N_3$ were given for the semicarbazone of the acid $C_8H_{10}O_5$.

gave several tenths of a gram of the acid $C_8H_{10}O_5$, with m.p. 97-99°.

Experiment 2. This was carried out under the same conditions as Experiment 1, but with 26 g of the cyclic ester. At the end of the hydrolysis, 29 g of dry permanganate was added to the solution, while the latter was being shaken and cooled. The consumption of permanganate was discontinued after the addition of the indicated amount.

It was computed that for the oxidation of the aldehydosuccinic (or 1-hydroxycyclopropane-2-carboxylic) acid, capable of being formed by the hydrolysis of 26 g of the ester, 14.6 g of $KMnO_4$ should be used up, and for the oxidation of the corresponding amount of the acid $C_8H_{10}O_5$, 29.2 g of $KMnO_4$ were needed. The observed consumption of permanganate thus corresponded to that computed for the acid $C_8H_{10}O_5$.

Succinic acid was obtained from the oxidation products by the method of treatment of the solution given in section III. It was identified by a mixed melting point test with known succinic acid.

Determination of the acid equivalent:

0.1252 g substance: consumed 4.85 ml 0.1 N NaOH.
Found: equiv. 60.
$C_2H_4(COOH)_2$. Computed: equiv. 59.

c) In the presence of barium carbonate

17.2 g (0.1 mole) of the ester was hydrolyzed under the same conditions with 120 ml of water in the presence of 20 g (0.1 mole) of $BaCO_3$.

After filtration, the solution was concentrated to a volume of 70 ml. To 7 ml of this solution there was added a solution of 1.5 g of semicarbazide hydrochloride. The dark yellow semicarbazone was purified by two crystallizations from water with animal charcoal. M.p. 197°. A sample mixed with the semicarbazone of the known acid $C_8H_{10}O_5$ gave no depression of the melting point.

The remaining solution was acidified with sulfuric acid and freed from acetic acid by distillation with steam, and then extracted with ether. The acid, $C_8H_{10}O_5$, which was obtained by the extraction in the form of a dark, viscous mass, did not crystallize, apparently because of the tarring which had taken place during its isolation.

In order to demonstrate its identity, it was converted into the semicarbazone, which after purification with bone charcoal had m.p. 198-199°. It was identified with the known semicarbazone.

d) In the presence of calcium carbonate

Experiment 1. 10.3 g (0.06 mole) of the ester was hydrolyzed under the same conditions in the presence of 6 g (0.06 mole) of $CaCO_3$. In order to complete the hydrolysis it was necessary to boil with rapid stirring for several days. The solution turned appreciably yellow toward the end of the hydrolysis.

The solution was filtered, evaporated to a volume of 70 ml, acidified, and extracted with ether in an extractor. This led to the formation of a thick, dark colored mixture of acids. Acetic acid was removed by heating the material in vacuum. The remaining oil did not crystallize upon standing or upon the addition of a drop of concentrated sulfuric acid. Crystallization took place only after long storage in a vacuum desiccator above sulfuric acid. After washing with cold ether and squeezing out on a porous plate, the crystals melted at 97°. A mixed sample with known acid of the composition $C_8H_{10}O_5$ showed no depression. Yield 0.25 g.

Experiment 2. 8.6 g (1/20 mole) of the ester was hydrolyzed under the same conditions in the presence of 6 g (0.06 mole) $CaCO_3$. After the solution had been filtered and concentrated, it was tested for the presence of aldehydoacid. The silver mirror reaction was positive. Upon mixing with a solution of semicarbazide hydrochloride there was an immediate precipitate of a semicarbazone with m.p. 186-187°, corresponding to the melting point of the semicarbazone with the composition $C_9H_{13}O_5N_3 \cdot 2H_2O$ (see IV,a). Two crystallizations from water containing bone charcoal and careful drying in vacuum over sulfuric acid raised the melting point to 197-198°. It was identified by a mixed test with the semicarbazone of the composition $C_9H_{13}O_5N_3$.

e) In the presence of sulfuric acid

Experiment 1. 5 g of the ester was hydrolyzed with 75 ml of 10% sulfuric acid with heating and stirring of the solution (4 to 5 hours). At the end of the hydrolysis, the solution was heated with stirring with 15 g of chalk for a period of 3 hours. After filtration from the excess of calcium carbonate, the neutral solution was evaporated in vacuum to a volume of 10 to 15 ml, and mixed with a solution of 3 g of semicarbazide hydrochloride in 10 ml of water. After 5 to 10 minutes, the semicarbazone precipitated. M.p. 177-178°. It was identified in a mixed melting point test with the semicarbazone of aldehydosuccinic acid (m.p. 178°) [6]. Yield 2.2 g (49% of theory).

The p-nitrophenylhydrazone, obtained from the solution under similar conditions of hydrolysis, had m.p. 177°, and did not give a depression with the p-nitrophenylhydrazone of aldehydosuccinic acid [6].

Experiment 2. 5 g of the ester was hydrolyzed under the same conditions with 10% sulfuric acid. Then, in contrast to the preceding experiment, the solution was boiled over an open flame with vigorous stirring with 25 g of calcium carbonate for several days. The solution was then filtered, acidified with 5 ml of concentrated sulfuric acid, and again filtered from the gypsum. The extraction of the acid solution with ether in an extractor gave a thick dark colored oil, which did not crystallize in vacuum. When the oil was mixed with a solution of semicarbazide acetate, a dark yellow semicarbazone was obtained with m.p. 187-188°, which corresponded to the melting point of the semicarbazone $C_9H_{13}O_5N_3 \cdot 2H_2O$ (see IV, a). When the semicarbazone was dissolved in a large quantity of hot water and the latter then cooled, the precipitate which separated consisted of a small amount of impure crystals, while the solution remained almost colorless.

This mother liquid was carefully concentrated in a vacuum desiccator, giving almost colorless crystals with m.p. 193-194°. After a second "crystallization", carried out by the same method, the melting point rose to 197-198°. A mixed test with the semicarbazone $C_9H_{13}O_5N_3$, obtained from the known acid $C_8H_{10}O_5$, melted at 197-198°.

SUMMARY

1. The reaction between vinyl acetate and diazoacetic ester in the presence of copper catalysts has been investigated. The ethyl ester of 1-acetoxycyclopropane-2-carboxylic acid has been obtained and studied. This compound has for the first time been able to provide an example of the introduction of the ester group, R-COO, into a three-carbon ring.

2. It has been shown that in the hydrolysis of the ethyl ester of 1-acetoxycyclopropane-2-carboxylic acid in acid medium, aldehydosuccinic acid is formed, and upon hydrolysis in the presence of alkaline reagents or neutral salts, the previously investigated acid, $C_8H_{10}O_5$, is formed.

3. On the basis of the data of hydrolysis, conclusions are drawn about

the extremely low stability of 1-hydroxycyclopropane-2-carboxylic acid, and a hypothesis is expressed about the most probable mechanism of transformation of this acid under the conditions for the hydrolysis of the cyclic ether.

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THE MOLECULAR REARRANGEMENTS OF ORGANIC COMPOUNDS IN THE LIGHT OF BUTLEROV'S THEORY OF STRUCTURE

(To the Memory of A. E. Favorsky)

S. N. Danilov

Chemical science is developing fruitfully on the basis of the periodic law of the chemical elements of D.I.Mendeleev, the structural theory of A.M.Butlerov, and the stereochemical theory of L. Pasteur and van't Hoff.

The general theory of the structure of chemical compounds (the theory of structure and chemistry in space) makes it possible to arrange a structural system, to explain and predict all the various compounds of carbon (organic substances) and the compounds of all the other chemical elements (inorganic compounds).

Organic chemistry entered on the path of especially rapid development from the time when in his lectures (1861), his communications, and his famous book, "Introduction to the Complete Study of Organic Chemistry" in 1863 and 1864, A.M. Butlerov [1] established strict laws for the union of atoms in molecules and the relationship between chemical properties and chemical structure, gave clear directions for the methods of discovering the chemical structures of compounds, and showed by experiment the incontrovertible qualities of the theory of structure as a genuine theory, capable not only of describing and explaining, but also of prediciting new substances and new transformations.

The group of "physical isomers", which had for a long time remained undecipherable, during the last quarter of the past century received definite spatial formulas in conformity with the theory of structure (substances with asymmetric carbon atoms, substances with asymmetric molecules, and geometric isomers).

The tetrahedral model of the carbon atom [2], which lies at the basis of stereochemistry, was for the first time definitely indicated (1862) by A.M.Butlerov, to be later (1867) discussed by Kekule. Butlerov considered it entirely possible to determine the spatial arrangement of the atoms in a molecule, and he must be considered as one of the founders of stereochemistry.

For brilliant successes of organic synthesis, the investigations of natural substances, and the chemistry of natural and synthetic high-molecular weight compounds, science is first of all indebted to the structural theory of Butlerov. Especially great merit for the confirmation and development of the theory of structure belongs to the famous and widespread Russian scientific chemical school of Butlerov, and chiefly to its founder, A.M.Butlerov (1828-1886).

Butlerov's theory of structure is closely related to previous theoretical viewpoints, to the attainments of organic synthesis, and to the knowledge of

natural organic substances. It resulted in a great revolution in chemical points of view, which was not immediately perceived by certain chemists [3], including Kekule, and it provided a firm basis for the further brilliant development of organic chemistry.

The remarkable experimental work of Butlerov and his profound theoretical conclusions attained a high degree of acknowledgement in Russia [4] and in the majority of cases abroad as well [5]. The tremendous influence of Butlerov's ideas and discoveries on the development of organic chemistry became still clearer in our century. However, some foreign chemists do not pay the necessary attention to the famous work of Butlerov, and do not indicate the priority of a number of discoveries by our other chemists. For example, this is so in the book by L. Fieser and M.Fieser on organic chemistry [6], which is a distortion of the history of chemistry, and indicates the lack of comprehension by these authors of the paths of development of organic chemistry. Unfortunately, sometimes even in our own land, there is through lack of understanding an underestimation of the role of Butlerov in the development of the theoretical ideas of organic chemistry (cf. the examples of underestimation of Butlerov given in the communication of Yu.A. Zhdanov) [7].

A. Kekule and A. Couper deserve credit for the fact that they drew conclusions about the tetravalence of the carbon atom (Kekule [8]) and about the possibility of its forming a bond (especially Couper [9]), or in other words of the joining of the carbon atoms to each other with the formation of carbon chains or ring shapes (theory of linkage of atoms), but they incorrectly estimated the significance of chemical formulas. Kekule had long been convinced of the impossibility of having any sort of reliable data concerning the mutual relations of the atoms inside molecules of complicated organic compounds. He assumed that rational formulas were only formulas for transformations, and that one and the same substance might possess various formulas. In his work he made contradictory and illogical assumptions, which he corrected under the influence of Butlerov's communications over a period of several years. Gradually, Kekule arrived at Butlerov's structural theory. This was excellently described by A.I.Gorbov in his splendid essay (1929), and had previously been described by V.V.Markovnikov and by foreign authors [10].

The great merit of Butlerov consisted of the fact that he had a clear understanding of the chemical structure of molecules, and drew from this, with excellent logic, conclusions concerning isomers and polymers, made predictions about new isomers on the basis of his structural theory, and presented his theory in an excellently demonstrable form. Already, in his famous "Introduction to the Complete Study of Organic Chemistry", in 1863 and 1864, and before that in lectures at Kazan University, he graphically developed a theory of structure which was applicable to all classes of organic compounds. It was precisely to him that the credit belonged for the fact that organic chemistry took the path of the determination of the structure of organic substances, of widespread organic synthesis, and of the the study of the roles of individual atoms and of groups of atoms in the properties of compounds. At the basis of his theory of structure lies Butlerov's conclusion [11]: "The chemical nature of a complicated molecule is determined by the nature and the amount of its elementary constituent parts, and by its chemical structure."

He said [12]: "We have not only the right, but also the obligation to speak of our molecules and atoms with all their relations as actually existing, and at the same time to retain our confidence that our judgements are not entirely abstractions without a real foundation. To the contrary, we can boldly assert that they have a definite relation to that which actually exists in the objective world".

During the recent period, there have appeared in our literature interesting reports (we must mention the communication of Yu.A.Zhdanov [7]) in which it is definitely shown again and again the theory of the structure of organic compounds by right should bear the name of Butlerov.

A very clear Butlerovian direction in organic chemistry has been developed from the eighties of the past century by one of the younger students of A.M.Butlerov: A.E.Favorsky (1860-1945), who accomplished much scientific work in the Soviet period of our great fatherland as well. The year 1950 completes 90 years from the date of birth, 50 years of editorial activity (as editor of the "Journal of the Russian Physico-Chemical Society", Chemical Section, from 1901, and of the "Journal of General Chemistry" from 1931 to 1945), and 5 years from the date of the death of a Hero of Socialist Labor, A.E.Favorsky.

In his work he logically developed the structural theory of Butlerov, chiefly by a study of the transformations of individual compounds into other compounds which were more stable under the given conditions, while keeping the same composition. In a number of cases he thus detected the reversibility of isomeric transformations.

Butlerov himself, and his students as well, from his example, even during the life of their teacher, began to undertake the investigation of molecular rearrangements, particularly of isomeric and tautomeric transformations, their explanation by the mutual influences of the atoms (A.M.Butlerov, V.V.Markovnikov, A.M.Zaytsev), and the polymerization reactions of unsaturated hydrocarbons. The investigation of isomeric and polymeric transformations received an especially great development in the work of Favorsky, who created a Soviet scientific chemical school.

The Phenomenon of Equilibrium Isomers

The changes in molecules, as a result of their instability under given conditions, take place in the direction of isomeric, tautomeric, and polymeric transformations. It is not difficult to note transitional cases from irreversibly proceeding isomeric transformations to typical tautomeric transformations, through isomeric transformations which are reversible under certain conditions.

Correctly ascribing to each substance a completely definite and at the same time single formula, Butlerov's theory of structure foresaw the transformations of substances without change of composition in various directions (isomerization and tautomerism), and with a change of composition along with the rearrangement of the original carbon skeleton (pinacoline rearrangement).

In 1877, A.M.Butlerov in his work on the polymerization of isobutylene showed [13] the spatial rearrangements of molecules of the type of isomeric and tautomeric transformations: "Because of the molecule's tendency to rearrangement, its entire mass, it is clear, will be subjected to reactions characteristic of one structure or the other, depending on the nature of the reagent to whose influence it is subjected, depending, so to speak, on the direction in which this reaction takes place." Here is given a clear determination of tautomeric transformations and of the general phenomenon of the equilibrium of isomers.

Butlerov regarded the molecules of a substance as being not in some sort of solidified forms, but in motion: "A chemical compound represents a definite form of relationship of the mobile atoms of its constituent parts," thus spoke Butlerov in his lecture to the Russian Physico-Chemical Society in 1879 [14].

In exactly the same way, D.I.Mendeleev, in his "London Lecture" of May 31, 1889, indicated that [15] "chemists must regard the atoms in the molecules themselves as being in motion, possessed of an active force, which is neither created nor destroyed, like matter itself."

In a communication of A.E.Favorsky [16] (1907), "The Phenomenon of Equilibrium Isomers in the Heating of Bromohydrins of the General Composition $C_nH_{2n+1}Br$ and $C_nH_{2n}Br_2$", he showed that it was possible to draw the conclusion from the first data with regard to time concerning isomeric transformations, that the transformation was completed only in one direction, i.e., that one form was transformed into the other, its isomer. The concept of stable and unstable molecules arose. The phenomenon of isomeric transformations was regarded as a consequence of the fact that the form which was structurally unstable changed its structure under favorable conditions to a more stable form. However, later, reversible isomeric transformations became known; especially clear examples were found by Favorsky in the transformations of the bromohydrins, so that the single concept of stable and unstable forms became insufficient. In his communication, Favorsky referred to the remarks of Butlerov, already quoted above, giving a broader picture of isomeric transformations, and with regard to this question he wrote the following: "Starting from the basis of the mechanical theory of heat and the laws of dissociation, first in his report on isobutylene (1877), and then in his lectures, which he delivered in Petersburg University in 1883-1885, Butlerov not only assumed the general possibility of existence of such isomeric forms, as could, like cyanic acid, with great ease be transformed into each other, but broadened the possibility of such transformations to all isomeric substances in the liquid and gaseous state."

It is precisely to Butlerov that the credit belongs for the prediction of tautomerism, otherwise known as desmotropism and pseudomerism, and for the discovery of the first examples of tautomeric compounds, like the ethers of the vinyl alcohols, [by Butlerov (1870), Eltekov (1877), and Favorsky (1888)], the vinyl alcohols themselves, and the aldehydes and ketones which corresponded to them.

The discovery of the phenomenon of tautomerism is often ascribed to Konrad Laar, although even the title of Laar's main communication [17] (1885), "On the Possibility of Several Structural Formulas for One and the Same Compounds", testified to the fact that his views were erroneous and were repetitions of the old views of Gerard and Kekule about chemical formulas. Butlerov indicated the phenomenon much earlier (1877), and after it had acquired the name of tautomerism, he also clearly characterized the mutual relations of the tautomers with regard to the theory of structure.

Laar began from the point of view of the oscillation theory, which did not correspond to the facts, assuming for one and the same substance different formulas. A formal character is also borne by the theory of oscillation of the "double bond" in benzene, according to Kekule, which is sometimes utilized for the theory of "resonance". Still more unacceptable are the views on the resonance hybrid structures of benzene [23]. In the light of the oscillation theory of the English scientist, Baly, he considered the properties of acetoacetic ester, denied the existence of any sort of definite structure, and referred to the appearance of an ultraviolet spectrum in his substance in the presence of alkali as if it were a resonance band [18]. However, further investigation of acetoacetic ester showed that the enol and keto forms actually existed as separate substances. In order to explain the color of organic substance, A.E.Porai-Koshits [19] at one time (1910) started from the oscillation theory, and later V.A. Izmailsky [20] assumed the presence of oscillatory disintegrations of the valence, a meso condition.

Having studied the shift of the bromine atom to a different carbon atom in mono and di-substituted bromine derivatives of hydrocarbons when these compounds were heated to a high temperature, with the formation of all the theoretically possible isomers, and having shown for the first time the reversibility of these

transformations, A.E.Favorsky compared the phenomena of isomeric and tautomeric transformations. He indicated the possibility of uniting the phenomena of tautomerism and the reversible isomeric transformations of ordinary isomers in a single general group of similar phenomena under the general name of "the phenomenon of equilibrium isomers", which had previously been used only for the phenomenon of tautomerism. In his paper, Favorsky drew many important conclusions about the nature of the phenomena of isomerism and tautomerism and about the role of the conditions of reaction.

Cases of isomerism during isomeric transformations are fairly frequent. Favorsky had long before shown the equilibrium and the reversibility of isomeric transformations in a number of acetylene and diethylene hydrocarbons, from monosubstituted acetylenes into disubstituted acetylenes or into asymmetrical disubstituted allenes upon heating with alcoholic alkali.

It has also been shown by Fittig [21] with regard to the compounds of the ethylene series that the transformations he had discovered, from β,γ-acids of the acrylic series into α,β-acids under the action of an aqueous solution of caustic potash, were reversible. The same phenomenon of reversibility was shown (in 1905) by A.E.Favorsky and M.G.Ageeva for the isomeric transformations of benzylethylene and methylphenylethylene.

Thus, Favorsky in his work clearly showed, as Butlerov had also pointed out, that to each substance there belongs its single formula, and that different reversible and irreversible transitions were possible between the given molecules of substances, depending on the conditions. As a result of molecular rearrangements, the first substance was transformed into a new substance, isomeric or tautomeric with it.

Long before, Bulterov had refuted the false claims then made by the known Russian chemist I.A.Menshutkin in his lectures on organic chemistry (1884) to the effect that "the molecules of chemical compounds could in all cases simultaneously consist of isomers". In his reply to this, in his lecture to the Russian Academy of Science on January 29, 1885, Butlerov [22] said:

"If I believe this, it is possible to believe that I can assume the simultaneous existence in one and the same molecule of different structures. Such an assumption would be obviously nonsense: the simultaneous existence of molecules of different structure in the mass of a substance is in no way in contradiction to an understanding of chemical structure ...

"On the assumption that the molecules have a tendency to rearrange themselves in one or another direction, chemical relations will be determined not by the amount of isomer, but by the nature of the reagent acting."

N.A.Menshutkin, brought up on the old theories, objected for several years to the theory of structure. He wrote down rational formulas, according to the method of Gerard, for the groups of atoms formed during substitution reactions, and he considered that these residues did not indicate the actual grouping of atoms in the molecule, but merely permitted the convenience of writing down on paper the various chemical transformations.

On this question, Butlerov wrote: "It is understood that the destruction of any condition which actually does not exist is an impossible thing. If we were to speak of the nonexistence of residues in the molecule, but of their existence on paper, then that would be just a play on words. In that case, the destruction of identity could also be carried out only on paper, without any relation to the chemical phenomena of nature, and there would be no explanation whatsoever of the actual phenomena in a substance."

These correct statements, made by A.M.Butlerov about the nature of compounds

and the meaning of chemical formulas, have been forgotten by the partisans of the theory of "resonance".

In the light of the theory of structure and the phenomena of isomeric and tautomeric transformations which are known to us, the so-called resonance theory, which has been expressed abroad and by various chemists among us in the USSR, is false.

It is not in the least possible to agree with the confused concepts developed in the theory of resonance [23] concerning the simultaneous coexistence in a single structure, as a result of so-called superposition, of numerous structures, which are unchangeable and untransformable. The ideas about the 'static and stable' "resonance" structures of molecules, and about unreal "hybrid" structures, are incorrect. It is impossible to consider the molecules as removed from the conditions in which they exist. It is impermissible to leave out of consideration during the course of the transformation of a substance the role of the reagents and the conditions. This, however, is the kind of thing we encounter not only in the theory of resonance, but sometimes also in the electronic structures of various authors.

However, the lack of foundation of resonance in organic chemistry can be seen even from the words of its fierce partisans, for example, G. Wheland, who in his book on the theory of resonance, writes: The idea of resonance is a speculative concept to a larger extent than other physical theories... It does not reflect any inner property of the molecule itself, but is a mathematical method invented by the physicist or chemist for his own convenience."

The theory of mesomerism, compared by C. Ingold to the theory of resonance [23], makes the assumption that not one of the possible structures can reflect the true conditions of a substance, and that the source of the energy of mesomerism is in electronic "degeneration", while the energy of 'perturbation' is similar to the energy of "resonance".

If the mesomeric structures of the English chemist, Ingold, are fictions, and do not exist in reality [23], then the hypothesis of mesomerism, as well as the hypothesis of resonance, is opposed to the theory of structure.

The famous molecular rearrangements discovered by Favorsky are without doubt important not only for synthetic organic chemistry, but also for the theory of organic chemistry.

Favorsky's rearrangements of a number of monosubstituted and bisubstituted acetylenes, allenes, and diethylene hydrocarbons in general, discovered by him in the period from 1884 to 1891, and developed also during the following decades, showed the special mobility, and the ability of such compounds to react.

The acetylene-allene-diene rearrangements discovered by Favorsky in open and ring-shaped chains and confirmed by other authors under various conditions, including the conditions of heterogeneous catalysis, are significant also with regard to halogen derivatives, as T.A.Favorsky and other students of A.E.Favorsky have developed. Such rearrangements will apparently be more and more frequently observed for other classes of unsaturated organic compounds as well.

It is impossible not to recall the famous rearrangements of Favorsky, which are extremely important for theoretical organic chemistry, of dichloroketones when treated with potash to give acids of the acrylic series, as well as of monohalogen ketones of the open chain and polymethylene series to give monobasic acids.

For a comprehension of the simultaneous oxidation-reduction reactions, which have a wide distribution in nature, there is especially great value in the discoveries of Favorsky and his coworkers, as developed from 1914 to 1928, of the

transformations of α-ketoalcohols into isomeric ketoalcohols, with a shift of the ketone group to the end of the chain (the production of an acetyl) [24].

Molecular rearrangements which are accompanied by the simultaneous phenomena of oxidation and reduction in one and the same molecule – with one part of the molecule being oxidized and another reduced, or with several molecules being involved (in this case, usually with the participation of water) – are of especial interest because of the fact that here there takes place a redistribution of oxygen and hydrogen respectively. The transformations take the direction during this process toward either the direct evolution of carbon dioxide, as during fermentation, or most frequently toward a greater reducibility of certain carbon atoms of the molecule and a lesser oxidizability of others.

In the benzil rearrangement and the Cannizaro reaction, water acts as the oxidizing-reducing agent.

A list of the most important intermolecular and intramolecular oxidation-reduction reactions is given by Danilov in his report in the collection on catalysis in 1949 [25].

The Course of Reactions and the Role of the Reagent

In the work of Favorsky there are many valuable results and a profound posing of the question of the courses of reactions, and of the roles of the intermediate forms and the reagent in the phenomena of isomeric transformations. The entire complexity of this question and its many-side nature can be seen from the espressions of Favorsky [26], especially if we trace his views on this question through the various decades.

In organic chemistry, these questions have been persistently posed by many authors and decided in various ways with respect to the most various reactions.

Isomeric transformations, considered in the Master's (1891) and the Doctor's (1895) Dissertations of A.E.Favorsky, were interpreted in the light of: 1) the formation of molecular compounds between the reacting molecule and the reagent; 2) the course of the reaction by way of intermediate products formed from the original molecules and having little stability under the conditions of the reaction.

In a preface to his Master's dissertation, A.E. considered that, "the views on the phenomena of isomerization, according to which they are to be understood as the result of a shift of the atoms of the molecule at the moment of its formation under the influence of the physical conditions and in the presence of a chemical reagent," were of little value. Of course he did not deny the possibility of isomerization under the influence of physical conditions, but he preferred "other concepts, according to which the phenomena of isomerization are to be regarded as a result of a number of chemical reactions".

This view was developed with especial persistence by Favorsky's scientific guide, Mikhail Dmitrievich Lvov, who was Butlerov's assistant in his university laboratory, and later Professor of Chemistry in the Petersburg Technological Institute.

This explanation was given by A.E. for the transformations of monosubstituted acetylenes in the presence of alcoholic alkali into disubstituted acetylenes by way of allene forms and for the transition of diethylene hydrocarbons (double bonds in positions 1 and 5) into divinyl hydrocarbons (double bonds in positions 1 and 3). We may note, incidentally, that in these researches, as well as in the work of L.M.Kucherov, which was carried out at the suggestion of A.E., on the isomerization of asymmetrical dimethylallene into isoprene, the greatest stability was observed in the divinyl grouping.

Aleksey Evgrafovich suggested that isomeric transformations in the C_nH_{2n-2} series took place as a result of the addition of the alcoholate of the alcohol to the triple and double bonds and the splitting off of alcohol in the reverse direction. The fruitfulness of this mechanism, which was based on the utilization of laws resulting from the theory of structure, is evident from the fact that in this way A.E. arrived at the idea that the allene hydrocarbons were intermediate compounds, and he actually demonstrated their isomerization into disubstituted acetylenes. It was found, however, that from allylene and allene there was formed a vinyl ether which was stable under the conditions of reaction (1888) and that this was not converted into a hydrocarbon upon heating. Its formation was also regarded by A.E. as an indication of the possibility of interpreting the isomeric transformations discovered as reactions of addition and cleavage of alcohol in the reverse direction.

The role of the reagent was especially clearly to be seen in the isomerization of disubstituted acetylenes into monosubstituted, which accumulated in the products of the reaction in the form of sodium derivatives (1887). The reversibility of the isomeric transformations of monosubstituted acetylenes and allenes was detected from the examples of isopropyl acetylene and dimethylallene.

As examples of other reactions which A.E. interpreted by means of intermediate compounds of the original substance with the reagent (sulfuric acid) there were the reactions involving the cleavage of water from α-glycols.

Basing his ideas on the formation in his laboratory of oxonium compounds from alcohols and α-glycols and from halogenated hydrocarbons, A.E. gave a mechanism for the dehydration of the α-glycols by way of oxonium compounds (1906 and 1913) with sulfuric acid or zinc chloride.

In his extraordinarily interesting lecture at the session of the Academy of Sciences in December, 1936, A.E. showed that despite the great success of the previous mechanisms for the isomeric transformations of acetylene hydrocarbons, expressed in the predictions of new phenomena, the accumulation of new data none the less forced the substitution of these mechanisms by new ones, "which corresponded more fully to the molecular dynamics of the C_nH_{2n-2} hydrocarbons, and influenced and directed their isomeric transformations." Aleksey Evgrafovich found it expedient to deny the hypothesis of intermediate products and to accept these transformations as intramolecular, precisely as a result of the shift inside the molecule of one or two hydrogen atoms from one carbon atom to another existing in the β-position. Many reactions, and especially the acetylene-allene-diene rearrangements were considered from the point of view of a shift of the hydrogen atoms. In certain cases, in the transformation of unsaturated hydrocarbons there takes place a shift of hydrogen atoms into the α-position and into the γ-position. Intramolecular rearrangements with mobile atoms and groups of atoms take place, of course, under the influence of the reagent and the conditions.

In the light of the view on isomeric and polymeric transformations according to which transformations take place intramolecularly, A.E. took under consideration many reactions, for example, the transformations into rings containing a triple bond or two double bonds.

In organic chemistry there are frequent explanations and predictions of the course of a reaction from the original product to the final product by way of intermediate compounds, on the basis of the theory of structure. Butlerov's theory of structure made it possible to foresee various transformations and various structures of the molecule, which could, however, take place in actuality only under definite conditions, such as were specified by experiment.

Very fruitful were the mechanisms developed in Favorsky's doctoral dissertation for the intermediate transformations of dichloroketones into acids of the acrylic series by way of chloro-oxides, and of monochloroketones into saturated acids by way of alcohol oxides. Alcohol oxide forms, similar to the alcohol oxide grouping in Butlerov's oxoctenol, were found to be very convenient for the demonstration of isomeric transformations of α-hydroxyketones into isomeric hydroxyketones (1928). Favorsky's mechanisms were utilized in the researches of Danilov and Venus-Danilova [27] for the prediction of the acid and hydroxyketone transformations of α-hydroxyaldehydes and α-halogenated aldehydes (1927-1929).

The hypothetical intermediate products did not always play an actual and exclusive role in these and other transformations, as was developed in detail [28] in a communication of Danilov and Venus-Danilova in connection with a study of the isomeric transformations of aldehydes and α-oxides into aldehydes and ketones.

An explanation of a reaction by means of intermediate compounds sometimes turned out to be completely unsatisfactory, especially in the case when the hypothetical intermediate substance could not exist under the conditions of the reaction. Thus, for example, under the conditions of the acid dehydration of α-glycols, α-oxides are not formed, although they were considered intermediate products in this reaction (K.A.Krasusky, 1902). The reactions can take place in various directions, in complete conformity with the theory of structure, sometimes with the formation of that substance from the reaction products which might have been called, as a result of its transformation into the final product, "intermediate". But in actuality, the role of intermediate products was filled only very seldom by compounds of the reagent with the original substances and the products of reaction. For example, it is completely impossible to regard the fact of the isomerization of aldehydes into ketones as a demonstration of the fact that when water is removed from α-glycols ketones are obtained necessarily through aldehydes. The nature of the reagent and the conditions are expressed in the very essence of the course of the reaction, and determine the course of the transformation, while the nature of the original substance sometimes has less influence on the composition of the reaction products than the reagent (for example, in the dehydration of α-glycols, the isomerization of α-oxides, the isomerization of aldehydes, etc.).

Under the action of a reagent or catalyst and other external conditions, a substance is transformed in one or several directions, sometimes with the formation of secondary product of reaction. The reagent in this case should not give with the original substances compounds which are stable under the given conditions, while in the opposite case, the reaction halts at the formation of these compounds, as is known, for example, in the reactions with $AlCl_3$, etc. (G.G.Gustavson, Friedel and Crafts).

A study of molecular rearrangements gives valuable material for the theory of homogenous and heterogeneous catalysis.

The Mutual Influence of Atomic Groups and Favorsky's Theory of Bond Strain

A.E.Favorsky was always interested [26] in an explanation of the properties of the bonds between the carbon and the other atoms, as well as in the properties of the bonds between different atomic groups situated near the main skeleton of the molecule (centers of unsaturation in multiple bonds, functional groups, ring-shaped groupings, etc.). He drew his conclusions about the properties of bonds on the basis of considerable experimental material on isomeric transformations.

It is known that centers of unsaturation and functional groups have an essential influence on the properties of atoms and atomic groups, while the properties of the latter in their turn are expressed in the properties of single, double, and triple bonds, or in the properties of the functional groups. A.M. Butlerov, and especially V.V.Markovnikov [29] were the first to pay attention to the mutual influence of atoms in the molecules and to the role of the conditions of reaction. This also exerted a decisive influence on the development of the theory of structure of organic chemistry as a whole. It created a basis for electronic structure, in particular in regard to the role of effects such as inductive, vicinal, etc.

In his Master's dissertation, on unsaturated hydrocarbons, and in a communication in 1918, on isomeric transformations of halogen hydrins of alcohols and of unsaturated compounds with open chains and with rings, A.E.Favorsky developed the concept of the strain of bonds, not in the sense of Bayer's strain, but as "a case of bonds between carbon atoms which exist in a condition close to that of dissociation." Here, as always, Favorsky logically applied and developed the theory of structure, broadening the views of Butlerov and Markovnikov on the mutual influence of atoms in molecules.

Let us note the main conclusions drawn by Favorsky on the mutual influence of atomic groups:

1. During isomeric transformations in the series of C_nH_{2n+2} hydrocarbons, "together with the enrichment of the molecule in methyl groups, there always takes place as far as possible a complete removal of the atoms of hydrogen from the central carbons, as a result of which there is a concentration of multiple bonds between the carbons."

2. "If we accept the mutual atomic influences as strains, the group of three hydrogen atoms in methyl will be more stable than the group of two atoms in methylene, and still more so than the one atom in the CH group" (Dissertation). And further, "The mutual influences of the atoms which compose the molecules of carbon compounds is expressed on the one hand in the tendency of the carbon atoms to polymerize and to separate from the compound in the form of carbon; and on the other in the counteraction to this tendency by the atoms of the elements joined to the carbon atoms" (Dissertation).

3. "There is reason to assume that in the molecules of carbon compounds the atoms of the elements joined to the carbon atoms are not exclusively under the influence of the latter, but influence each other" (Dissertation).

4. "In the molecules of organic compounds it is necessary to assume the existence of a strain in the bonds between carbon atoms which are close to the point of their dissociation. The strain will be greatest with single bonds and least with triple. In this respect, double bonds will have an intermediate position". (Communication, 1918).

5. "The strain in single bonds in saturated compounds reach their greatest value in cyclic groupings, and about quaternary carbon atoms in open chains". (Communication, 1918).

6. "When multiple bonds appear in a ring, the strains are increased both for the single bonds and for the multiple bonds. A tertiary radical present at a multiple bond increases the strain, and increases the tendency to addition of that carbon atom to which it is adjacent" (Communication, 1918).

In this communication of 1918 he drew many interesting conclusions about the mutual influences of atoms in molecules and predicted, for example, the properties of cyclopropene, later described by N.Ya.Demyanov and M.N.Doyarenko.

We can consider the stability of oxygen bridges, in α-oxides, etc., in the light of the theory of strain.

We must note that in judging the transformations of molecules in the light of the theory of strain, it would be incorrect not to take account of the role of the reagent. Thus, in the isomerization of α-oxides [28] it is possible to obtain an aldehyde or a ketone, depending on the concentration of sulfuric acid (S.N.Danilov, E.D.Venus-Danilova, 1927).

The mutual influence of atoms in a molecule during its transformations cannot help depending on the external conditions and the reagent.

It is impossible to regard the characteristics of a substance as self-induced – the stability and the strain of bonds, the mobility and the tendency of atoms and atomic groups to shift places, and also the so-called volume relationships of radicals – without taking account of external conditions and the particular reagent. A substance acquires instability in the presence of a reagent, as well as in the conditions of catalytic-fermentation, thermal, photolytic, and other action.

For a study of the properties of substances in chemically pure form, physical methods of investigation, in particular, by means of radiant energy, have already been of great aid and promise to be of very much more. The application of these methods under the conditions in which chemical reactions were carried out, taking place both simultaneously and consecutively, encountered many difficulties. We may expect, from a study of substances by means of radiant energy, an explanation of the nature of chemical affinity and of the chemical bond.

In the light of the theory of the strain of bonds and of intramolecular oxidation-reduction it is also possible to clarify such phenomena as the explosive transformations of molecules, the combustion of gunpowder, the decomposition of molecules under the conditions of alcoholic and other fermentations, the reactions of polymerization and condensation, etc.

The mutual influences of atoms and the influences of the attractions of molecules should be especially sharply expressed in high molecular weight substances.

The instability of molecules is shown in their tendency to polymerization and polycondensation, frequently accompanied by isomeric transformations (Lebedev, 1912).

High-molecular weight compounds, which are characterized by chain or three-dimensional structures, have considerably extended the boundaries of the theory of structure proposed by Butlerov.

S.V.Lebedev [30], the creator of the method of preparing divinyl rubber, logically applied the theory of structure of Butlerov to the chemistry of natural and synthetic rubbers. Lebedev belonged to the scientific school of Favorsky, and even in 1912 he correctly characterized the molecules of rubber as great chain-shaped structures, while other chemists (the German chemist Harries, etc.) for a long time continued to ascribe to rubber and to high molecular weight substances in general small ring-shaped molecules, which were supposed to have a tendency to associate in large aggregates.

The determinations of the molecular weights of high-molecular weight compounds by different existing methods, although it did not give fully accurate data, partly because of the lack of chemical uniformity of the high-molecular weight compounds, did show the high values of their molecular weights. Up to this time there has been no possibility at all of finding the dimensions of the molecules of those high-molecular weight substances, which are distinguished by

their insolublility and their lack of tendency to soften, and are characterized by three-dimensional molecular structures. "Three-dimensional" molecules are reminiscent in their structure of the molecules of diamond, which consist of very many carbon atoms, whose number is unknown.

It would be incorrect in the chemistry of high-molecular weight compounds to fail to recall the molecule which some years ago was suggested by the German chemist Bergman (1925). This was opposed to the theory of structure, which predicted many varieties of molecules. The atomic-molecular structure of matter is confirmed by all the scientific experience in the course of centuries. The properties of high-molecular weight compounds, in particular their physico-mechanical properties (stability to rupture, lengthening, elasticity of materials) depend on the dimension of the molecules, on the degree of branching of the chains, on the order of joining of the links, etc., as well as on the packing of the molecules in the material, as for example in fiber (the role of intermolecular attraction, hydrogen bonds, such are assumed to be in the cellulose fiber, etc.). Opinion exists to the effect that there is a slight destruction of chain-shaped molecules of high-molecular weight compounds even under conditions of mechanical action (during the stretching of films and threads, during pulverizing in a colloid mill).

The decision of fundamental questions concerning the nature of the chemical bond and chemical affinity, in addition to a profound study of chemical properties and the transformations of organic substances by chemical methods, should be fundamentally assisted by the broad utilization of methods based on the application of radiant energy (spectra, etc.).

A great success of science is the discovery of the electron, the elucidation of the structure of atoms of chemical elements, and the consideration of chemical valence and chemical affinity in the light of the electronic point of view.

The future will show to how great a degree chemical affinity and the characteristics of chemical transformations can be explained by the properties of the electron. The sharp differences in the properties of chemical elements give us reason to assume that the chemical properties of substances are not merely determined by electrons, and that "chemical affinity is a special form of motion", to use the words of Yu.A.Zhdanov [7].

The modern electronic viewpoint has in many ways fruitfully developed Butlerov's theory of structure. However, only further investigation can throw a bridge across from the electronic structure of the atom to the electronic explanation of the properties and the complicated transformations of molecules of organic substances.

We still face a great task in explaining precisely how the properties of the electron are expressed in relation to the chemical properties and the chemical transformations of molecules.

There is special importance in the question as to whether electronic isomerism is possible, and as to what are the essential distinguishing characteristics of the suggested electronic isomers, and proceeding still further, there is electronic tautomerism, such as has been suggested, for example, by V.V.Razumovsky [32], in which the role of hypothetical electronic displacement is expressed.

We must still await further more profound developments also of the general question of the mutual influences of atoms and atomic groups in molecules, taking the necessary account of the role of the reagent and the conditions during the chemical transformations.

The explanation of the role of "effects", like, for example, the "vicinal effect" [4] of D.V.Tishchenko [33], which reflects the influence of neighboring atoms in halogen derivatives, etc., is doubtless closely related to the rules in organic chemistry discovered by V.V.Markovnikov, A.M.Zaytsev, F.M.Flavitsky, A.P. Eltekov, A.E.Favorsky, and others of our outstanding chemists. This direction of science has been expressed in his electronic structures by A.M.Berkengeim [34].

On the ninetieth anniversary of his activity (1861-1951), from the time of the famous lecture of A.M.Butlerov on September 19, 1861 – "Something about Chemical Structure" – Butlerov's theory of structure now stands firmly on its foundations, strengthened and developed, its content broadened, while on it is being created the complicated and incredible structure of organic chemistry.

Its future development must lead to further broad generalizations with regard to the chemical properties and transformations of substances and to a clear concept of chemical valence and chemical affinity.

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ON THE SYNTHESIS, STRUCTURE, AND TRANSFORMATIONS OF β-2-ETHOXY-1(6)-NAPHTHOYLPROPIONIC ACIDS

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In the condensation of 2-ethoxynaphthalene with succinic anhydride in the presence of $AlCl_3$ in a solution of nitrobenzene, Swain, Todd, and Waring [1], obtained two isomeric ketoacids: β-(2-ethoxy-6-naphthoyl)-propionic, whose structure was determined by its transformation into the known β-(2-hydroxy-6-naphthoyl)-propionic acid [2], and a keto acid whose structure remained undemonstrated. However, the similarity in the chemical properties of the latter acid (its transformation upon heating with hydrobromic acid into a β-naphthol, the absence of any reaction for the carbonyl group) with the properties of β-(2-methoxy-1-naphthoyl)-propionic acid [3] gave the authors reason to suppose that this acid was β-(2-ethoxy-1-naphthoyl)-propionic acid.

We also carried out the condensation of 2-ethoxynaphthalene with succinic anhydride not only in nitrobenzene medium, but also in carbon disulfide medium. An accurate knowledge of the structure of the keto acids obtained had great significance for us.

Upon carrying out the reaction in nitrobenzene we obtained results which were fundamentally in agreement with those of Swain, Todd, and Waring. We obtained two isomeric ketoacids with the same properties as these investigators had described, but we found it more convenient to carry out the separation of the isomeric acids by changing them into their ethyl esters, as the melting points and solubilities of the ethyl esters of the ketoacids were different, while these properties of the acids themselves were almost identical.

The structure of β-(2-ethoxy-6-naphthoyl)-propionic acid was confirmed by us by its oxidation to the known 2-ethoxy-6-naphthoic acid. In order to determine the structure of the second keto acid, we also attempted to utilize oxidation *, but did not obtain clear results. We showed the presence of the carbonyl group in the supposed β-(2-ethoxy-1-naphthoyl)-propionic acid by reduction according to the Clemmensen method; the ethoxynaphthylbutyric acid thus formed was considerably more stable than the original keto acid: upon heating the ethoxynaphthylbutyric acid with hydrobromic acid, only the hydrolysis of the ethoxyl group took place, and the acid side chain was retained. This opened to us a method for the determination of the structure of the second keto acid.

In accordance with the description of Short, Stromberg, and Wiles [3], we obtained β-(2-methoxy-1-naphthoyl)-propionic acid, and after reducing this by the Clemmensen method and then hydrolysis of the methoxy group, we obtained γ-(2-hydroxy-1-naphthyl)-butyric acid, which was identical with the hydroxynaphthyl-

* Short, Stromberg and Wiles [3], determined the structure of β-(2-methoxy-1-naphthoyl)-propionic acid by oxidizing it to 2-methoxy-1-naphthoic acid.

butyric acid prepared by us in the same way from the supposed γ-(2-hydroxy-1-naphthyl)-butyric acid. The identity of the two hydroxynaphthylbutyric acids demonstrated with sufficient clarity the structure of β-(2-ethoxy-1-naphthoyl)-propionic acid.

Upon condensing 2-ethoxynaphthalene with succinic anhydride in carbon disulfide medium we obtained almost exclusively only the β-(2-ethoxy-1-naphthoyl)-propionic acid.

EXPERIMENTAL

Condensation of 2-ethoxynaphthalene with succinic anhydride in nitrobenzene. In a three-necked round-bottomed flask, fitted with a reflux condenser and a mechanical stirrer, there were placed 120 g of ethoxynaphthalene, 100 ml of nitrobenzene, and 66 g of succinic anhydride. Using stirring, with external cooling, there was gradually added 120 g of $AlCl_3$ (the addition was continued for about 10 hours). The mixture was then allowed to stand at room temperature for 8 hours to 40-45°. After cooling, the contents of the flask were poured over ice, and acidified with concentrated hydrochloric acid. The reaction mixture was transferred to a separatory funnel, the nitrobenzene layer separated, the aqueous layer extracted with ether, and the latter added to the nitrobenzene solution. The nitrobenzene layer was treated with a 4% solution of caustic soda. The alkaline solution was removed and shaken with a small amount of ether, and the ether layer removed; the alkaline solution was carefully heated a short time in order to remove the rest of the ether. The alkaline solution was transferred to a separatory funnel, and a small amount of benzene was added. It was then acidified with hydrochloric acid until there was an acid reaction to Congo red. The tar which thus separated went into the benzene, and the keto acid separated in the form of an amorphous precipitate, which was filtered with suction on a Buchner funnel, and washed several times with small portions of benzene. There was obtained 67 g of a mixture of the keto acids, with melting range 125-132°.

In order to separate the isomers from the acid mixture, it was subjected to esterification by heating for a period of 6 hours with 300 ml of absolute ethyl alcohol and 30 ml of sulfuric acid. After the usual treatment, a mixture of the ethyl esters was obtained. This was subjected to recrystallization from ethyl alcohol. The ethyl ester of β-(2-ethoxy-6-naphthoyl)-propionic acid was soluble with more difficulty in alcohol and precipitated first, with m.p. 94-95°. 14.4 g was obtained. The ethyl ester of β-(2-ethoxy-1-naphthoyl)-propionic acid remained in the mother liquids. After repeated recrystallization, the m.p. was 51-52°. 11.2 g was obtained. In addition, there remained a small amount of a mixture of the ethyl esters with m.p. 66-67°.

When the esters obtained were saponified with a 6% alcoholic solution of caustic potash, there was obtained 12.8 g of β-(2-ethoxy-6-naphthoyl-propionic acid with m.p. 162-163°, and 9.3 g of β-(2-ethoxy-1-naphthoyl)-propionic acid, with m.p. 163-164°.

The condensation of 2-ethoxynaphthalene with succinic anhydride in carbon disulfide. In a three-necked round-bottomed flask, fitted with a mechanical stirrer and a reflux condenser, there were placed 800 ml of carbon disulfide, 120 g of ethoxynaphthalene, and 60 g of succinic anhydride. The reaction mixture was cooled externally with ice, and while stirring went on, there was gradually added 104 g of aluminum chloride. After the addition of the latter, the stirring was continued for an additional period of 8 hours, and the carbon disulfide then carefully poured off. The carbon disulfide was driven off from the reaction mass that remained by heating on a water bath for 10 to 15 minutes. Ice and hydrochloric acid were then added. The precipitate that formed was shaken with a small amount of ether and filtered with suction on a Buchner funnel. After the

precipitate had been washed on the funnel with small portions of ether, the substance was dissolved in a 4% solution of caustic soda, and the traces of carbon disulfide and tarry substances were removed from the alkaline solution with ether. The alkaline solution was filtered and acidified with hydrochloric acid. The keto acid which precipitated out was filtered with suction and washed, while suction was carefully applied, with small portions of ether and benzene. There was obtained 30 g of material with m.p. 157-158°; after recrystallization from alcohol, there was obtained 25.3 g of β-(2-ethoxy-1-naphthoyl)-propionic acid with m.p. 162-164°.

The ether benzene solution was washed with alkali and further treated to give 8.5 g of a mixture of the ketoacids with m.p. 124-130°. From this, esterification and further saponification gave 1.6 g of 2-ethoxy-6-naphthoylpropionic acid and 1.2 g of 2-ethoxyl-1-naphthoylpropionic acid.

The ethyl ester of β-(2-ethoxy-6-naphthoyl)-propionic acid. 1.5 g of the ketoacid with m.p. 162-163°, which was obtained in greater amount from the condensation of 2-ethoxynaphthalene with succinic anhydride in nitrobenzene, 35 ml of absolute ethyl alcohol, and 1.4 ml of sulfuric acid were heated on a water bath for a period of 6 hours. After the usual treatment and recrystallization from alcohol, the ethyl ester of β-(2-ethoxy-6-naphthoyl)-propionic acid was obtained with m.p. 94-95°; it was a colorless crystalline substance, fairly readily soluble in organic solvents.

3.125 mg substance: 8.245 mg CO_2; 1.940 mg H_2O.
Found %: C 71.95; H 6.94.
$C_{18}H_{20}O_4$. Computed %: C 71.96; H 6.71.

Upon saponification of the ethyl ester with a 6% alcoholic solution of caustic potash, there was obtained the unpurified ketoacid with m.p. 160-161°; after recrystallization from alcohol, the m.p. was 164-165°.

The ethyl ester of β-(2-ethoxy-1-naphthoyl)-propionic acid. 0.7 g of the ketoacid with m.p. 162-164°, obtained by the condensation of 2-ethoxynaphthalene with succinic anhydride in carbon disulfide, 15 ml of absolute ethyl alcohol, and 0.5 ml of sulfuric acid were heated for a period of 6 hours on the water bath. After the usual treatment, and three recrystallizations from alcohol, colorless crystals were obtained with m.p. 51-52°. They were readily soluble in organic solvents and insoluble in water.

4.204 mg substance: 11.096 mg CO_2; 2.580 mg H_2O.
Found %: C 71.98; H 6.73.
$C_{18}H_{20}O_4$. Computed %: C 71.96; H 6.71.

Upon saponification of the ester, the ketoacid with m.p. 160-162° was obtained. After recrystallization from alcohol, the m.p. was 164-165°. When the melting point was determined for a mixed sample of this ketoacid with the ketoacid obtained in a similar manner in the preceding experiment, a considerable depression was obtained. The melting point of the mixture was 139-140°.

The oxime of β-(2-ethoxy-6-naphthoyl)-propionic acid. 0.7 g of β-(2-ethoxy-6-naphthoyl)propionic acid, 0.54 g of hydroxylamine hydrochloride, 0.77 g of barium carbonate, and 20 ml of alcohol were heated on a water bath for a period of 6 hours. The hot alcoholic solution was decanted from the $BaCO_3$ precipitate, and the latter was boiled several times with new portions of alcohol. The alcoholic solutions were united and the alcohol driven off until the precipitation of the oxime began. The solution was cooled and 5 ml of water was added. The oxime which precipitated was filtered off and recrystallized from alcohol.

A colorless crystalline ma... ... m.p. 145-146° was obtained.

3.8 mg substance: 0.171 ml N_2 (16.50°, 736 mm).
Found %: N 5.14.
$C_{16}H_{17}O_4N$. Computed %: N 4.88.

The oxidation of β-(2-ethoxy-6-naphthoyl)-propionic acid. 2 g of β-(2-ethoxy-6-naphthoyl)-propionic acid was oxidized with a solution of sodium permanganate, prepared from a solution of 18 g of caustic soda in 30 ml of water by passing in chlorine until there was a gain in weight of 12 g. The oxidation was carried out by heating on the water bath to 70° for a period of 3 hours. At the end of the oxidation, the solution was cooled. From it there precipitated the sodium salt of 2-ethoxy-6-naphthoic acid, from which, by acidification, there was obtained 2-ethoxy-6-naphthoic acid. After recrystallization from alcohol, the m.p. was 205-206°.*

Upon heating the 2-ethoxy-6-naphthoic acid thus obtained with a mixture of hydrobromic and acetic acids, 2-hydroxy-6-naphthoic acid was obtained with m.p. 240-241°. Upon treating this with acetic anhydride, the acetyl derivative was formed, with m.p. 224-225°**.

The ethyl ester of β-(2-hydroxy-6-naphthoyl)-propionic acid. 1 g of β-(2-hydroxy-6-naphthoyl)-propionic acid with m.p. 228-230°***, 15 ml of absolute alcohol, and 0.5 ml of sulfuric acid were boiled on a water bath for a period of 6 hours. At the end of the reaction, the alcohol was driven off in vacuum, and water was added to the residue, which was then extracted with ether. The ether solution was washed with a solution of sodium bicarbonate and dried with sodium sulfate. The residue from the driving off of the ether was crystallized from alcohol. The ethyl ester of β-(2-hydroxy-6-naphthoyl)-propionic acid was obtained with m.p. 139-140.5° It was very soluble in organic solvents and in aqueous solutions of caustic alkalies.

2.710 mg substance: 7.030 mg CO_2; 1.449 mg H_2O.
Found %: C 70.76; H 5.98.
$C_{16}H_{16}O_4$ Computed %: C 70.59; H 5.88.

γ-(2-Hydroxy-6-naphthyl)-butyric acid. a) In a round-bottomed flask with a reflux condenser there were placed 1.2 g of β-(2-hydroxy-6-naphthoyl)-propionic acid, 13 ml of glacial acetic acid, 8 ml of toluene, 8 ml of hydrochloric acid (1:1), and 7.5 g of amalgamated zinc. The reaction was carried out by boiling over a gauze for a period of 20 hours, 3 portions of hydrochloric acid (1:1) of 1 ml each being added during the course of the reaction. At the end of the reaction, the cooled reaction mixture was extracted with ether and the ether solution was washed with a 4% solution of caustic alkali. When the alkaline solution was acidified, a substance precipitated, which after crystallization from aqueous alcohol melted at 154-157° and was identified with the γ-(2-hydroxy-6-naphthyl)-butyric acid obtained by splitting off the methoxy group in (2-methoxy-6-naphthyl)-butyric acid (see following expt.).

b) In a flask with a reflux condenser, there were placed 0.5 g of (2-methoxy-6-naphthyl)-butyric acid****, 10 ml of glacial acetic acid, and 16 ml of

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*According to the data of Hudson [4], 2-ethoxy-6-naphthoic acid melts at 204-205°.

**These compounds were previously obtained by Royle [5].

***β-(2-Hydroxy-6-naphthoyl)-propionic acid was obtained by us from β-(2-methoxy-6-naphthoyl)-propionic acid by the cleavage of the methoxy group upon heating with a mixture of hydrobromic and acetic acids.

****2-methoxy-6-naphthyl-butyric acid with m.p. 134-135° was obtained by us from β-(2-methoxy-6-naphthoyl)-propionic acid by reduction with zinc amalgam and hydrochloric acid in a solution of glacial acetic acid and toluene.

hydrobromic acid, and the reaction mixture was boiled on a calcium chloride bath for a period of 3 hours. At the end of the reaction, the solution was evaporated to dryness in vacuum, and the residue dissolved in a 10% solution of caustic soda. Upon acidification of the alkaline solution, 2-hydroxynaphthyl-6-butyric acid precipitated out. After crystallization from aqueous alcohol, this was in the form of a colorless crystalline material with m.p. 154-157°, very soluble in ether, alcohol, and acetone.

3.257 mg substance: 3.717 mg CO_2; 1.775 mg H_2O.
Found %: C 72.99; H 6.10.
$C_{14}H_{14}O_3$. Computed %: C 73.04; H 6.09.

γ-(2-Ethoxy-1-naphthyl)-butyric acid. In a round-bottomed flask joined to a reflux condenser there were placed 1.5 g of β-(2-ethoxynaphthoyl-1)-propionic acid, 10 ml of toluene, 10 ml of hydrochloric acid (1:1) and 8 g of amalgamated zinc. The reaction was carried out by boiling over a gauze for a period of 20 hours. During the course of the reaction, 1 ml portions of hydrochloric acid (1:1) were added three times. At the end of the reaction, the mixture was cooled and extracted with ether. From the ether layer the acid which had been formed was extracted with a 4% solution of caustic potash. Upon acidification of the alkaline solution with hydrochloric acid, a tarry substance precipitated. Four recrystallizations from aqueous alcohol gave the 2-ethoxy-naphthyl-1-butyric acid in the form of colorless crystals which melted at 93-94°, and were readily soluble in ether, carbon tetrachloride, dichloroethane, and alcohol.

3.495 mg substance: 9.575 mg CO_2; 2.200 mg H_2O.
Found %: C 74.72; H 7.04.
$C_{16}H_{18}O_3$. Computed %: C 74.42; H 6.98.

γ-(2-Methoxy-1-naphthyl)-butyric acid. 1.5 g of β-(2-methoxy-1-naphthoyl)-propionic acid (obtained according to directions [3]), 8 g of amalgamated zinc, 10 ml of glacial acetic acid, 10 ml of toluene, and 10 ml of hydrochloric acid (1:1) were boiled for a period of 20 hours. Upon cooling, the mixture was extracted with ether, the ether solution washed with a 4% solution of NaOH, and the alkaline solution acidified with dilute hydrochloric acid. There precipitated an oily substance, which gradually hardened. After numerous recrystallizations from alcohol, the m.p. was 81-83°.

2.851 mg substance: 7.698 mg CO_2; 1.704 mg H_2O.
Found %: C 73.64; H 6.69.
$C_{15}H_{16}O_3$. Computed %: C 73.77; H 6.56.

γ-(2-Hydroxy-1-naphthyl)-butyric acid. a) The hydrolysis of the methoxyl group in γ-(2-methoxy-1-naphthyl)-butyric acid. 0.1 g of γ-(2-methoxy-1-naphthyl)-butyric acid, 3.2 ml of hydrobromic acid, and 2 ml of glacial acetic acid were boiled for a period of 3 hours. The acids were distilled off in vacuum, and the residue dissolved in aqueous alkali. The solution was filtered and hydrochloric acid (1:1) added. The precipitate which came out was recrystallized from alcohol, and had m.p. 136.5-137.5°.

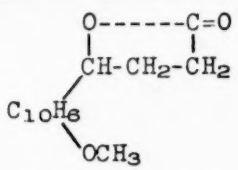
4.258 mg substance: 11.412 mg CO_2; 2.280 mg H_2O.
Found %: C 73.09; H 5.99.
$C_{14}H_{14}O_3$. Computed %: C 73.04; H 6.09.

b) The hydrolysis of the ethoxyl group in γ-(2-ethoxy-1-naphthyl)-butyric acid. 0.4 g of γ-(2-ethoxy-1-naphthyl)-butyric acid, 13 ml of the hydrobromic acid, and 7 ml of glacial acetic acid were boiled for a period of 4.5 hours. The acids were driven off in vacuum and the residue dissolved in alkali. The solution was filtered and acidified. The precipitate which formed melted at 127-132°. After 3 recrystallizations from alcohol, a colorless crystalline substance was obtained with m.p. 135-137°.

3.120 mg substance: 8.352 mg CO_2; 1.687 mg H_2O.
Found %. C 72.83; H 6.05.
$C_{14}H_{14}O_3$. Computed %. C 73.04; H 6.09.

In a determination of the melting point of a mixture of the substances obtained according to methods (a) and (b), no depression was observed.

γ-(2-Methoxy-1-naphthyl)-butyrolactone,



In a glass vessel, fitted with a mechanical stirrer, there were placed 1.75 g of β-(2-methoxy-1-naphthoyl)-propionic acid and 35 ml of a 5% solution of soda. Then there was gradually added, with stirring over a period of 8 hours, 20 g of sodium amalgam (20%). At the end of the addition of the latter, the stirring was continued for an additional 2 hours and the mercury then removed. A vaseline-like oil which had been held by the sodium amalgam was extracted with ether. After removal of traces of ether, the alkaline solution was acidified with 10% hydrochloric acid until there was an acid reaction to Congo red, and the reaction mixture was boiled for 10 minutes. The substance which precipitated out on cooling was extracted with ether, and the ether solution was washed with soda, with a 3% solution of sodium bicarbonate, and then with water, and dried with sodium sulfate. The material which remained after the ether was driven off was recrystallized from alcohol. There was obtained 0.35 g of a colorless crystalline substance with m.p. 126-128°. It was very soluble in ether and in acetone.

3.643 mg substance: 9.918 mg CO_2; 1.801 mg H_2O.
Found %: C 74.25; H 5.53.
$C_{15}H_{14}O_3$. Computed %: C 74.38; H 5.79.

γ-(2-Ethoxy-1-naphthyl)-butyrolactone. In a glass vessel, fitted with a mechanical stirrer, there were placed a solution of 5 g of β-(2-ethoxy-1-naphthyl)-propionic acid in 80 ml of a 10% solution of Na_2CO_3, and there was added gradually, over a period of 8 hours in small portions, 50 g of 20% sodium amalgam. During the addition of the amalgam, a 10 ml portion of water was added after each hour. After the addition of all the amalgam the stirring was continued for an additional 2 hours. The reaction mixture was then transferred to a separatory funnel, the mercury separated, and the vaseline-like oil extracted with ether. After the removal of traces of ether, the alkaline solution was acidified with 3% hydrochloric acid until there was an acid reaction to Congo red, and then boiled on a gauze for a period of 10 to 15 minutes. The cooled reaction mixture was extracted with ether, and the ether solution washed several times with a 3% solution of soda until upon acidification of the latter no more than a slight cloudiness was formed. The ether solution was dried with sodium sulfate and the ether distilled off. The residue, after recrystallization from alcohol, was in the form of a colorless crystalline substance with m.p. 127-128°, very soluble in ether and in alcohol.

3.759 mg substance: 10.330 mg CO_2; 2.130 mg H_2O.
Found %: C 74.95; H 6.34.
$C_{16}H_{16}O_3$. Computed %: C 75.00; H 6.25.

γ-(2-Methoxy-6-naphthyl)-butyrolactone. In a glass vessel, fitted with a mechanical stirrer, there were placed 5 g of β-(2-methoxy-6-naphthoyl)-propionic acid, and 85 ml of a 10% solution of soda. To the solution obtained there was gradually added, with stirring, 50 g of sodium amalgam (20%). The reaction was

then carried out as for the production of γ-(2-Methoxy-1-naphthyl)-butyrolactone. After recrystallization from ethyl alcohol the lactone of (2-methoxy-6-naphthyl)-hydroxybutyric acid melted at 121-123°. 0.7 g was obtained as a colorless crystalline substance, very soluble in ether and acetone.

2.898 mg substance: 7.901 mg CO_2; 1.536 mg H_2O.
2.870 mg substance: 7.812 mg CO_2; 1.500 mg H_2O.
Found %: C 74.35, 74.25; H 5.93, 5.85.
$C_{15}H_{14}O_3$. Computed %: C 74.38; H 5.79.

γ-(2-Ethoxy-6-naphthyl)-butyrolactone. In a glass vessel, fitted with a mechanical stirrer, there was placed 4.2 g of β-(2-ethoxy-6-naphthoyl)-propionic acid, dissolved in 70 ml of a 10% solution of soda. Then there was added gradually, over a period of 4 to 5 hours, 40 g of 20% sodium amalgam (excess over thecry 10 times). The reaction took place at room temperature, and during its course, 10 ml of distilled water was added each hour. After the addition of all the amalgam, the stirring was continued for an additional two hours.

Further treatment and isolation of the lactone was exactly the same as in the preceding experiment. The lactone which was obtained after driving off the ether was recrystallized from alcohol. The m.p. was 125-126°. The lactone was insoluble in water and fairly readily soluble in organic solvents.

2.710 mg substance: 7.459 mg CO_2; 1.494 mg H_2O.
Found %: C 75.06; H 6.17.
$C_{16}H_{16}O_3$. Computed %: C 75.00; H 6.25.

SUMMARY

1. In the preparation of 2-ethoxy-1-(6)-naphthoyl propionic acids by the condensation of 2-ethoxynaphthalene with succinic anhydride in the presence of $AlCl_3$, changes were made, in comparison with the information in the literature, in the methods of preparation and separation of the isomeric keto acids formed.

2. The structures of the 2-ethoxy-1-(6)-naphthoylpropionic acids have been confirmed and they have been made to undergo different transformations.

3. Y-[methoxy-(ethoxy)-naphthyl-1(6)]-butryolactones have been obtained.

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